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Planning of a year-round experiment on trans-Arctic acoustic transmission in the framework of the program "Arctic Climate Observation using Underwater Sound" (ACOUS) [1] is a complex problem involving, not only, scientific and technical issues, but requiring consideration, also, of the financial aspects. According to the ACOUS proposal, the NRAD's vertical array is one which can be used as the first receiving system for the year-round experiment, and this array should be deployed in the Lincoln Sea in the spring of 1996. Therefore, the main problem at the first stage of designing the experiment is to develop an optimum scheme for trans-Arctic acoustic transmissions to the Lincoln Sea.

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PLANNING OF DEPLOYMENT OF AN AUTONOMOUS SOURCE FOR YEAR-ROUND ACOUSTIC MONITORING OF THE ARCTIC OCEAN

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INTRODUCTION

Planning of a year-round experiment on trans-Arctic acoustic transmissions in the framework of the program "Arctic Climate Observation using Underwater Sound" (ACOUS) [1] is a complex problem involving, not only, scientific and technical issues, but requiring consideration, also, of the financial aspects. According to the ACOUS proposal, the NRAD's vertical array is one which can be used as the first receiving system for the year-round experiment, and this array should be deployed in the Lincoln Sea in the spring of 1996. Therefore, the main problem at the first stage of designing the experiment is to develop an optimum scheme for trans-Arctic acoustic transmissions to the Lincoln Sea.

This complex problem can be separated into the following issues:

1. Selection of sites which are acceptable for acoustic monitoring of long-term changes in the Arctic Ocean, for the deployment of the source;
2. Modelling of the acoustic propagation along the paths considered (estimation of the modal propagation loss and travel times);
3. Consideration of the logistical issues: accessibility and conditions of the regions for the source installation, transportation problems, installation method, power supply, etc.;
4. Estimation of the cost of possible installation schemes and designs of the transmitting system;
5. Designing of the most acceptable scheme for the source installation, and estimation of the main parameters of the transmitting system design;
6. Determination of the optimum parameters of the source, signals, and the transmission schedule.

The points outlined above cannot be considered separately from one another, because the solution to one has a bearing on the answers to the others. At this stage of the study we are considering, in general, all possible variants for the installation of the source, since it enables us to select the most acceptable, and least expensive way, to prepare the first stage of the experiment with the acoustic transmissions at one path. However, this preliminary analysis should also support planning for the next steps of the experiment on the trans-Arctic multi-path, acoustic monitoring network .

I. POSSIBLE LOCATIONS OF THE ACOUSTIC SOURCE

Observations of the bottom relief in the Arctic Ocean show that a very limited number of regions are acceptable for the installation of a source, for trans-Arctic acoustic transmissions. These regions are located at the edge of the northern coastal shelf of the Arctic archipelagos - Spitsbergen, Franz Josef Land (FJL), and Severnaya Zemlya. A source provided with a battery power supply can be also moored at the top of the Lomonosov and Alpha underwater ridges. Figure 1 shows the regions of the Arctic bottom which are most suitable for deployment of the source. Because of the strong attenuation of low frequency acoustic signals in shallow water, in the shelf regions, the source should be placed as close as possible to the edge of the continental slope. For the deep-water basin, we assume that the ocean depth acceptable for mooring the source should not exceed 2 km.

For Arctic conditions, in general, one can consider three ways of installing the source:

1) Providing the source with power via cabling to a coastal power station. This approach is suitable for the near-shore regions only and requires the use of a special cable layer;
2) Mooring an autonomous source (with a battery power supply) on the sea bottom, from the board of a ship;
3) Mooring an autonomous source from the drifting ice.

The most appropriate choice depends, first of all, on the ice conditions in the region of the source installation, since the feasibility of operating both the ship and an ice camp depends on those conditions. An overview of the very different ice conditions in Spring and Autumn in seven regions considered, is presented in Table 1. Over the Yermak plateau 200 km north of Spitsbergen the ice conditions are very changeable in both the winter and summertime. In the Arctic summertime (August-October) the ice north-west of Spitsbergen melts, making this region suitable for ship operations each year. The width of this ice-free zone varies from year to year, but ordinarily does not exceed 100 km. In the Arctic winter (February - April) the ice cover over the Yermak plateau is continuous, but fractured, making it difficult to find a suitable ice floe for setting up camp.

In the northern parts of the Franz Victoria and St.Anna Straits, the sea surface is covered with ice year-round. In winter and spring there, the ice cover is permanent and firm enough to create a drifting ice station. In summertime the ice becomes strongly fractured, but is too dense for the operation of a ship without the assistance of an icebreaker. The summertime margin of the Arctic ice pack in these straits migrates between 80^0 and 82^0 North, which is due, mostly, to synoptic changes in the wind direction.

The ice conditions at the northern coast of Severnaya Zemlya are very unpredictable. The Great Siberian Polynya which exists year-round in the Laptev Sea, east of Severnaya Zemlya, very strongly influences the ice conditions around the archipelago. In summertime there is very probably open water north of the Arktitcheskiy cape (the northernmost point of Severnaya Zemlya). However, in this region operation of a ship is highly unlikely without the support of an icebreaker, which would have to guide the ship through the Vil'kitskiy strait, or through the dense ice in the North Kara Sea. On the other hand, in winter, the prolonged southern wind can extend the northern edge of the Great Siberian Polynya up to the Arktitcheskiy cape, which makes any operations from the drifting ice very difficult there.

The possible methods being proposed for the installation in the regions considered, are summarised in Table 1. This table shows that the installation of the source with the help of a ship - both for cabling to the shore, or for autonomous mooring - is very problematic in all of the regions. In this case, the only reliable way is the use of an icebreaker as the primary operating vessel, or as an assisting one, but this would be very expensive. Therefore, we propose to moor the source from the drifting ice.

From the point of view of acoustic monitoring of long-term changes in the Arctic ocean, the appropriate choice of the first acoustic path for the initial year-round acoustic measurements is as important as the logistic issues already considered. On the one hand, the acoustic path should intersect those Arctic ocean regions which are subject to large-scale temperature changes of a climatic character, rapid and intense in nature. On the other hand, it is desirable to have the path far from the ocean zones of great mesoscale activity and seasonal variability, since these kinds of variations present noise in acoustic detection of climatic changes. One of the main origins of climatic changes, in the Arctic Ocean, is thought to be variations in the temperature and volume of the Atlantic water inflow through the Fram strait. Therefore, the acoustic measurements at the Spitsbergen - Lincoln Sea path should be most efficient for detecting those variations. However, at the beginning of the path, over the Yermak plateau, the ocean dynamic processes - like internal waves - are more intensive than those in the Central Arctic Basin [2]. Moreover, the water temperature and ice conditions over the Yermak plateau are subject to very strong seasonal variations. This means that changes in the acoustic signals at the Spitsbergen - Lincoln Sea path, may reflect local variations in the water temperature in the vicinity of the source, rather than possible climatic changes over the whole path [3]. The opposite situation can be anticipated at the Alpha Ridge - Lincoln Sea path. There, the seasonal and mesoscale variations are relatively small. However, this path crosses the ocean region at the furthermost limit of the Atlantic water stream. Hence, the climatic "signal" incoming with the Atlantic water may be detected at that path after multiple years of measurements. Looking for a compromise, one can consider two paths - Franz Victoria Strait-Lincoln Sea and St. Anna Strait-Lincoln Sea. Both paths cross the main stream of the Atlantic water circulation not very far from its inflow into the Arctic basin through the Fram Strait. Each of those paths traverses the Nansen basin, where the abnormally warmed Atlantic water was observed in the icebreaker and submarine scientific cruises of 1994 and 1995 [4]. On the other hand, the synoptic and seasonal dynamics in the northernmost parts of the Franz Victoria and St.Anna straits are expected to be much less intensive than those near the Fram strait. In these regions the internal waves have an energy level lower than that at the Yermak plateau, by a factor of 5-10 [5, 6].

II. MODELLING OF THE ACOUSTIC PROPAGATION

For modelling we chose two frequencies of the acoustic signal - 20 and 30 Hz, - and two alternative depths of source deployment - at 100 m and on the bottom. We took into consideration the frequency of 30 Hz, since that frequency was expected to be acceptable for the trans-Arctic transmissions at paths of 1 Mm (Fig.1), while building a source of that frequency is a less complicated task than that for the 20 Hz source. A source depth of 100 m has been chosen, because it is close to the maxima of the eigenfunctions of modes 1-3 in both the shallow-water regions like the St.Anna Trough (Fig.2), and the deep-water regions (Fig.3). The deployment of the source on the bottom was considered, since this option simplifies, considerably, the method of mooring the source. Furthermore, in that case, a tracking system for locating the source position is not necessary.

We calculated the modal propagation losses and travel times at four paths - 1, 2, 3, and 6, shown in Figure 1. The bottom profiles along these paths are shown in Figures 4 - 7 respectively. We split each profile into 5-7 parts and approximated the bottom profiles within each part by a linear function. Then we used the coupled mode method [7] for calculation of the sound field and the modal parameters. The modal travel times were determined for the regular component of the modes, which does not include the sound energy scattered from the rough ice cover, and excited at the sloping bottom due to mode coupling. The bottom acoustic properties were chosen to be uniform, and the same for all the paths. We applied the data taken from an experimental acoustic study of the characteristics of sediments in the Franz Victoria Trough. These data are as follows: density relative to water - 1.8; compressional wave speed - 1800-1850 m/s; shear wave speed - 300-350 m/s; compressional wave attenuation (the imaginary part of the wave number relative to the real part of that) - 0.01; shear wave attenuation - 0.02. Experiments on low-frequency acoustic propagation have shown that in the St. Anna Strait the bottom sediments have approximately the same acoustic parameters. Unfortunately, we have no data on the acoustic properties of the bottom along the deep-water parts of the paths, and in the Lincoln Sea. In the deep-water Arctic waveguide the bottom properties are not significant for long-range acoustic propagation, while in the Lincoln Sea the bottom affects all modes propagated. Hence, the assumption of uniform properties of the bottom may induce additional errors in calculations. Those errors concerning modal attenuation could be considerable, if the bottom sediments in the Lincoln Sea have a structure different from that in the Franz Victoria trough. The group velocities and propagation times of the low-order modes are not so sensitive to the bottom properties as the modal attenuation.

In calculations, ice scattering was taken into account with the use of the ice scattering theory developed in [8]. We used the one-scale model of ice roughness instead of the two-scale model proposed in [8], because separate data for level and ridged ice over the Arctic basin are not presently available. Ice statistics parameters were taken from ice echo-sounding data from submarines [9, 10]. We chose the winter ice conditions as the hardest for sound propagation. Each of the paths was split into a number of sections of constant ice statistic parameters. Coarse mapping of the mean ice thickness over the paths, assumed for calculations, is schematically shown in Figure 1. The ice thickness increases from 3 m at the shores of the Eurasian Arctic archipelagos to 6 m in the Lincoln sea. According to [9] and [10], we determined the standard deviation of the lower ice boundary roughness as 0.65 of the mean ice thickness. The standard deviation for the upper ice boundary was assumed to be 0.25 of the lower one. We also assumed that the roughness correlation length is 30 m - in the Lincoln Sea, and 40 m - over all of the rest of the paths. The acoustic properties of the ice were taken as constant along all of the paths and corresponding to winter conditions, as follows: density - 0.9; compressional wave speed - 3000 m/s; shear wave speed - 1800 m/s; compressional wave attenuation - 0.01; shear wave attenuation - 0.035.

Table 1. Possible regions of the deployment of the acoustic source for year-round transmissions.

Region	Coordinates	Sea depth	Ice cover condition		Cabling the source from shore	Installation of the source from a ship	Installation of the source from drifting ice
			Spring	Autumn			
1. North of Svalbard (Yermak Plateau)	81.5-82^0 N 7-9^0 E	500-600 m	Permanent, but fractured ice cover	Very fractured and unstable ice, low probabability of open water	Possible in the autumn with the assistance of an icebreaker	Possible in the autumn with the assistance of an icebreaker	Possible in the spring
2. North-West of FJL (Franz-VictoriaTrough)	81.5-81.7^0 N 39-41^0 E	400-450 m	Stable ice cover, acceptable for setting up camp	Unstable, but dense ice cover dependent on weather conditions	Possible in the autumn, but guaranteed only with the assistance of an icebreaker	Possible in the autumn, but guaranteed only with the assistance of an icebreaker	Possible in the spring
3. North-East of FJL (St. Anna Trough, shelf)	81.3-81.5^0 N 68-70^0 E	500-600 m	Stable ice cover, acceptable for setting up camp	Permanent, but fractured ice	Not very likely	Very problematic	Possible in the spring

4. North-East of FJL (St. Anna Trough, continental slope)	82-82.3^0 N 69-71^0 E	1500-2000 m	Stable ice cover, acceptable for setting up camp	Permanent, but fractured ice	Not very likely	Very problematic	Possible in the spring
5. North of Severnaya Zemlya (shelf and continental slope)	81-81.5^0 N 94-96^0 E	500 - 1500 m	Unstable and unpredictable due to the Great Siberian Polynya	Very likely open water - permanent but changeable Great Siberian Polynya	Not very likely without the assistance of an icebreaker	Very problematic without an icebreaker in navigating the North Kara Sea	Impossible in the autumn, problematic in the spring
6. Alpha Ridge	84.0-84.5^0 N 155-160^0 W	1500-2000 m	Permanent ice cover	Permanent ice cover	Impossible	Possible only from an icebreaker	Possible in the spring and in the autumn
7. Lomonosov Ridge	86.3-86.7^0 N 140-141^0 E	1200-1500 m	Permanent ice cover	Permanent ice cover	Impossible	Possible only from an icebreaker	Possible in the spring and in the autumn

Figures 8-19 present the results of acoustic propagation modelling. To simplify the interpretation of the theoretical results obtained, we added the pattern of the TAP experimental results into each of the plots showing the numerical estimation of modal propagation loss. The TAP data display the average propagation loss of modes 1-4 in the phase-coded signals received at a depth of 60 m, at the ice camp SIMI. With such modal propagation loss a signal level of 195 dB, in transmission, provided about 20 dB SNR of modes 1-3, and 0 dB SNR of mode 1, at a single hydrophone after coherent averaging over approximately 3000 sec.Hz. Such coherent averaging allowed us to obtain almost 30 dB in gain, which seems to be close to the maximum achievable. Thus, the TAP data can be used as a good indicator for estimating the power capacity of a source required for trans-Arctic transmissions.

Figures 8 and 9 show that an acoustic signal at a level of 195 dB, and 20-30 Hz in frequency transmitted at the Yermak plateau, could be heard in the Beaufort Sea, if the source were to be deployed at the optimal depth of mode excitation. However, one should treat these results with care, since the bottom acoustic model assumed for modelling, implies low acoustic absorption, which may not be in agreement with the actual bottom properties.

The same signals transmitted from Franz Victoria and St.Anna Straits will be received in the Lincoln Sea with the high SNR (Figures 11, 12, 14, and 15). The comparison of the upper and lower plots in these Figures shows that placing the source at the optimal depth provides additional an 15-20 dB in the signal level at the receiving site, relative to signals from a source deployed on the bottom. These figures also demonstrate that the propagation losses of modes 1 and 2 at 20 Hz are less than those at 20 Hz by 30 and 20 dB respectively. As follows from Figure 14a, for acoustic transmissions along the St. Anna Strait - Lincoln Sea path, the power capacity of the source could be reduced by almost 15 dB relative to 195 dB of the TAP signal level, which should be sufficient to provide the same SNR of modes 2 and 3 as in the TAP signals, and about 5 dB of gain for mode 1.

The St. Anna Trough has a relatively flat bottom with a depth of 500 m in the southern part, and about 600 m - in the northern part. Northward, the trough turns slowly into a gradual continental slope falling into the deep Arctic Basin. The acoustic source can be moored either at the northern edge of the shallow water region, or over the continental slope. To determine the influence of the shallow water part of the path upon the modal propagation loss, we compare modelling results for paths 3 and 4 (see Table 1 and Fig. 1). Path 4 start is shorter than path 3 by 100 km, and starts from the continental slope at a depth of 1500 m. Figure 17 shows that the difference in the modal propagation loss calculated for path 3 and path 4 is very small, and negligible for the modes of low numbers. Thus, it seems more reasonable to deploy the source in the shallow arc of the trough, not far from the continental slope, since the installation of the mooring system in shallow water should be much easier than in deep water.

In calculations for the Alpha Ridge - Lincoln Sea path we obtained the lowest transmission loss of the acoustic modes (Fig. 17), since this path is shorter than the others considered. Evidently, the source planned for deployment at Alpha Ridge can be much less powerful at 20 Hz than the TAP source which produced 250 W of acoustic power in transmission. We can, certainly, plan to reduce the signal level for transmissions from Alpha Ridge to 185 dB, which means a reduction in the source power capacity from 250 W to 25 W!

Figures 10, 13, 16, and 19 demonstrate the numerical estimates of the modal propagation times calculated for paths 1, 2, 3, and 6, respectively. At path 1 the arrivals of modes 3 and 4 overlap the arrival of mode 1 (Fig. 10a). However, modes 1 and 2 should dominate in the signal received in the Lincoln Sea, as follows from Figure 8a. Hence, the arrivals of those modes could be resolved in pulse-like signals with a pulse width of 1 sec or less. At paths 2, 3, and 6 the arrival of mode 1 at both 20 and 30 Hz is delayed, so radically, relative to the arrivals of the other meaningful modes, that it cannot be a problem to separate this mode from the pulse signal in the time domain. On the other hand, at 20 Hz the difference in the travel times of modes 2-5 is so small, that it becomes very difficult to separate these modes from one another, by the arrival time. To do this, it is necessary to reduce the pulse width to 0.2 seconds (at a frequency bandwidth of about 5 Hz). At 30 Hz the arrival of mode 2 can be resolved with a narrower bandwidth of the signal. Thus, for the paths considered, we believe that it is proper to recommend the use of spatial filtering of the acoustic modes at the receiving site with the help of a vertical array.

III. POSSIBLE INSTALLATION SCHEMES AND ASSOCIATED EXPENSES

For the power supply of the source one can consider either connecting the source to a coastal station using a low- resistance cable, or using autonomous batteries. According to Table 1, we have, generally, three variants for the installation scheme:

1. Cabling and deploying the source from a special ship on the coastal shelf, or on the continental slope at a depth of 600 to 2000 m, with power supplied by a cable from the shore;
2. Deploying the source from on board a ship on the coastal shelf, or on the continental slope at a depth of 600 to 2000 m with a battery power supply;
3. Deploying the source from the drifting ice on the coastal shelf , or on the continental slope at a depth of 600 to 2000 m with a battery power supply;
4. Deploying the source from the drifting ice on top of the Alpha and Lomonosov underwater ridges, at a depth of 1500 to 2000 m with a battery power supply.

In general, the mooring design is similar for the cabled and autonomous sources. It consists of an anchor, a mooring rope, an acoustic source with a controlling unit, an apex float, and a tracking system for locating deviations of the source. In the case of the battery power supply, the mooring rope could be wireless and synthetic, and the controlling unit would have batteries, while in the coastal power supply one would use a low-resistance cable for mooring, instead of the synthetic rope. Obviously, the deployment of the source right on the bottom, or close to it, does not require tracking of the source position. Let us now consider the main expenses involved in the proposed installation schemes.

A. CABLE POWER SUPPLY FROM THE SHORE

Suitable locations for the deployment of the shore-based power station can be found at Spitsbergen (at the Henlopen Strait), on the western coast of Franz Josef Land (at Dezhnev Bay, Alexandra Land), on the eastern coast of Franz Josef Land (at Graham Bell Island), and at Severnaya Zemlya (on the Arktitcheskiy Cape). Further, for our cost estimation, let us assume that the source is to be placed as far as 150-200 km from the coastal station.

Before deploying the source and cabling, it is necessary to build a shore-based power station, and to deliver the equipment required for this. Basically, the equipment should include power generators, fuel tanks, a tractor and/or other means of transportation which could be used for pulling the thick and heavy cable from the water on to the beach. Laying of the cable from the mooring to the shore can be carried out only by means of a special cable layer. The Russian Northern fleet, based in Murmansk, has such a vessel called "ZEYA". However, this cabling ship is allowed to operate only in ice-free regions, which seriously restricts the time period and the appropriate area to be planned for the installation of the source.

The protection of the power cable at the shore-line and in the shallow coastal water is another serious problem because the motion of coastal ice and the drift of icebergs in the coastal waters, can destroy the cable. To minimize the chance of destruction of the cable by icebergs, it should be laid on the bottom in a steep trough, in a deep bay. For protection against coastal ice motion, it is best to bury the cable in the ground or under a special concrete shield starting at the shore-line to a depth of 30-40 m. Obviously, this would require additional complex equipment and considerable expense.

Table 2 shows the preliminary estimates of the cost of installation of an acoustic source, with a cable power supply from the shore.

TABLE 2

1. Cost of Equipment:		
Power supply cable 200 km length,	($1600/200 km)	$320,000
Diesel power generators,	($7.500x2)	$15,000
Tractor		$15,000
Lodges,	($5,000x4)	$20,000
Tanks for fuel,	($5,000x4)	$20,000
Diesel fuel,	($400x100t)	$40,000
Equipment for the source installation (winches, anchor, floats, mooring cable, etc.)		$30,000
Expedition equipment and provision		$35,000
Total Equipment Cost:		$505,000
2.Transportation Costs:		
Delivery of equipment to Murmansk		$25,000
Lease of a cargo ship for 12 days to deliver the expedition equipment to the coastal station:		
2 days of loading, ($10,000 per day), and		$20,000
10 days of work, ($12,500 per day)		$125,000
Lease of the cabling ship "ZEYA" for 20 days, ($5.000 per day*)		$100,000
Aircraft reconnaissance and guiding of the cable layer for 20 hours (@ $1000 per hour)		$20,000
Additional service cost		$10,000
Total Transportation Cost:		$300,000

3.Salary of Expedition Staff:

Salaries for the expedition staff for 45 days for building the coastal station and installation procedure (14 persons)	$42,000
Salaries of the coastal station staff during the year-round experiment (4 person	$96,000
Total Salaries:	$138,000

Total Expedition Cost:	$943,000

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* - price as of spring 1995

We have considered the cheapest, but most unlikely and least reliable variant of cabling in the ice-free area, without any protection of the cable at the shore-line. Certainly, the assistance of an icebreaker for both the cargo ship and the cable layer, as well as building the protection for the coastal cable, would considerably increase the final cost arrived at, in Table 1.

All costs given in Table 1 have been estimated from prices as of autumn 1995.

B. BATTERY POWER SUPPLY (INSTALLATION FROM A SHIP)

In favourable ice conditions in the Fall, the installation of an autonomous source with a battery power supply can be carried out by means of a ship. It may be done in the ice-free zone north-west of Svalbard and, perhaps, north-west of Franz Joseph Land. However, the ice conditions in those regions are very changeable and unpredictable due to the strong influence of local weather. This makes planning of the ship expedition difficult without the assistance of an ice breaker. We assume that the autonomous source will be deployed at a depth of 100 m with mooring at a depth of 500-600 m. The main expedition expenses (without the lease of an icebreaker) areshown in Table 3.

TABLE 3

1. Delivery of equipment to Murmansk	$25,000
2. Lease of a ship for the source installation for 20 days ($5,000 per day*)	$100,000
3. Equipment for the source installation, (anchor, floats, mooring rope, etc.)	$30,000
4. Additional ship service cost	$10,000
5. Expedition equipment and provisions	$20,000
6. Salary of the expedition staff (7 persons) for 30 days	$14,000
Total Expedition Coast:	$199,000

* - price as of spring 1995

C. BATTERY POWER SUPPLY (INSTALLATION FROM THE ICE)

Instead of a ship, one can use the Arctic ice as a platform from which to install the source. This gives us an additional chance to select the proper place for deploying the source, in the Arctic regions covered with dense and solid ice. In the springtime the ice conditions allow us to build an ice camp for the source installation, at the edge of the continental slope in the Franz Victoria Strait and in the St. Anna Strait. Moreover, operations from the drifting ice make it possible to deploy the source in the Central Arctic Basin, on the Lomonosov and Alpha Ridges.

For estimation of the operational expenses, let us consider the less expensive variant of deploying the source at the continental slope, at 150-200 km from the shores of the Arctic archipelagos (regions 1, 2, 3, and 4 in Table 1). At the first stage of the expedition it will be necessary to organise an intermediate coastal base at one of the islands - Spitsbergen, Alexandra Land (FJL), or Graham Bell (FJL), and then to deliver the expedition equipment there, from Moscow. One may use either the facilities of the Norsk Polar Institute at Spitsbergen, or the polar station "OMEGA" at Alexandra Land, or the available lodges at Graham Bell Island. The next step is to build an ice camp and to transport the expedition staff and equipment there. The approximate estimates of the expenses required for the source installation from the drifting ice are shown in Table 4.

TABLE 4

1. Transportation Costs:	
Rent of an aeroplane - IL-76 (AN-72) for transportation of the expedition staff and equipment from Moscow to the coastal base, there and back	$100,000
Rent of a helicopter - MI-8 for transportation of the expedition staff and equipment from the coastal base to the ice camp, there and back	$50,000
Total Transportation Cost	$150,000
2. Equipment:	
Equipment for the source installation (winches, anchor, floats, mooring rope, etc.) -	$40,000
Expedition equipment and provisions	$25,000
Total Equipment Cost	$65,000
3. Accommodation at the coastal base (10 days):	
Hotel at Longyearbyen,	$12,000
or repair of the OMEGA ice station at Alexandra Land, *	
or lease of the lodges at Graham Bell Island	($3,000)
4. Salary of the expedition staff (14 persons) for 45 days	2,000
Total Expedition Cost:	$270,000

* - we have no reliable information on the present condition of the "OMEGA" ice station.

The cost of construction of the transmitting complex with a source tracking system is not included in all of the estimates of the total expedition expenses given above.

IV. PRINCIPAL SCHEME OF DEPLOYMENT OF AN AUTONOMOUS SOURCE

The preliminary estimation of the cost of the different installation schemes considered in the previous section, shows the autonomous source design to be the most preferable, since it is the least expensive both for the installation procedure and the year-round operation of the source. Furthermore, the results of modelling the transmission loss given in Section 2, show that the deployment of the source at the proper depth in the water column, rather than on the bottom, will allow us to optimize the acoustic power of the source required for transmissions. In that case, we could extend the life-time of the batteries, and optimize the weight and size of the source.

Thus, the optimal scheme of the source deployment can be represented as shown in Figure 20. The mooring system consists of an anchor, a mooring rope, a transmitting system (acoustic source, controlling unit, and batteries), and an apex float. The controlling unit includes, generally, a precise clock, a signal generator, and a power amplifier. The controlling unit should, also, contain an acoustic transceiver with a controller, if an acoustic positioning system is to be used for tracking the horizontal deviations of the source due to changes in the current.

As previously indicated, a mooring system with an autonomous acoustic source can be deployed either in the shelf regions, at depths of 400-600 m, or at the tops of the underwater ridges in the Central Arctic Basin, at a depth of 1500-2000 m. Therefore, we propose two versions of the mooring scheme - for the shallow- water and deep-water regions, with depths of 600 m and 2000 m respectively. We assume that the source will be deployed at a depth of 100 m allowing for almost optimal excitation of the modes of the lowest numbers 1, 2, and 3.

For further development of the mooring design, it is necessary to estimate the behaviour of the system in the current expected in the regions of the source deployment, because, firstly, the accuracy of travel time measurements at the acoustic paths depends on the accuracy of the horizontal positioning of the source, and, secondly, the acoustic characteristics of the source are very sensitive to depth variations. Figures 21-26 show the numerical estimates of the horizontal and vertical deviations of the source moored by a kevlar rope, 500 and 1900 m in length, for different current velocities 5, 10, 20, and 30 cm/s and different values of the mooring tension. On all of the plots the lower curve relates to the maximal tension allowed for the specified rope diameter. This value of tension is presumed to be two times less than the tensile strength. In calculations, we assumed the uniform vertical distribution of the current velocity, since we have no reliable information on the current profiles in the regions proposed for the source deployment. According to [11], in the Central Arctic, over the Alpha Ridge, current velocity below 100 m can be less than 5 cm/s. However, this value is a modelling prediction derived from the water density stratification, rather than an experimental result. Most of the experimental measurements of the current velocity in the St.Anna Strait were made from the drifting ice, without exact navigation. Therefore, the data of these measurements can be used only for very rough estimation of the upper limit of current velocity. According to such preliminary estimations, the current velocity should not exceed 20 cm/s in the upper water layers, and 10 cm/s - at the bottom.

For further analysis we have to determine the upper limit of the accuracy required for horizontal positioning of the source. Let us assume that the resolution of acoustic measurements of changes in the mean water temperature along a 1 Mm path, would be no worse than 1 millidegree. In terms of sound speed, it means approximately 0.005 m/s of variation which is equivalent to change of a 1 Mm distance by 3.5 m. Assuming variations of the water current by direction and speed, we should limit the range of uncontrolled horizontal deviations of the source by 1.7 m. As can be seen in Figures 21 and 23, such stability of the short (500 m) mooring system could be provided by an appropriate apex float, if the maximal current velocity were to be about 10 cm. For the long (2 km) mooring (Fig.25), the assumed horizontal deviation of the source could be achieved, if the water current were to be either very slow, less than 2 cm/s, or very stable.

The problem of controlling unacceptable deviations of the source can be solved with the use of an acoustic tracking system which would locate the horizontal position of the source. Such a system consists, basically, of three acoustic transponders firmly deployed near the bottom, and an acoustic transceiver installed on to the mooring system, near the source. In the case of deployment of the mooring system from the drifting ice, the acoustic transponders are preferred because they have the capability of self-locating. It means that those transponders dropped from the drifting ice on to the bottom, should be able to determine the distances between each other, and transmit these data to the transceiver. This should considerably simplify the procedure of deployment from the drifting ice. After the self-location cycle, the tracking system starts its regular operation according to the schedule of low- frequency transmissions. The source position should be located by the tracking system just before the transmission, then encoded and transmitted with the low frequency acoustic signal to the receiving site of the path. Encoding of the source navigation data can be achieved by additional coding of M-sequences planned for the trans-Arctic transmissions. The principles of optimal coding of the M-sequences allowing for transmission of additional information will be considered in future studies.

SUMMARY

Based on the results of this stage of planning the year-round acoustic transmissions aimed at monitoring of large-scale long- term changes in the Arctic ocean, we propose the following recommendations on planning for the experiment:

1. The Franz Victoria Strait - Lincoln Sea, and St. Anna Strait -Lincoln Sea paths are the most acceptable for starting year-round acoustic transmissions at the first stage of the creation of an acoustic monitoring network in the Arctic. Placing an acoustic source in the Central Arctic (at the Alpha and Lomonosov Ridges) is a good idea for planning multi-year measurements at the next stage of the project.
2. The acoustic source should be an autonomous one and have a battery power supply, thus greatly reducing the total cost of the experiment.
3. Operating from the drifting ice in Spring is the most appropriate and reliable way to install the source.
4. Disregarding some of possible logistical problems, one can state that the northern edge of the St. Anna Strait is the most suitable place for deployment of the source.
5. We recommended that the source be deployed at a depth of about 100 m, which should provide the optimal excitation of the most meaningful low-order modes, and optimize the power capacity of the source, while deployment of the source on the bottom will require 20 dB more acoustic power than the possible optimal value.
6. A signal frequency around 20 Hz is much more preferable than that of 30 Hz , for trans-Arctic transmissions.
7. The recommended level of the signals planned for transmissions to the Lincoln Sea is about 190 dB at 20 Hz, which is found to be sufficient for reliable reception of the signals, as well as for measuring the modal characteristics.
8. At the paths considered, the time delay between the arrivals of deep-water modes (2, 3, and further) is so small, that one should use either the broadband signals with a

bandwidth not less than 5 Hz, or spatial filtering with a vertical array, for decomposition of those modes in the signal.

9. A mooring system deployed in the shallow water, at a depth of 600 m, or less, should keep the vertical deviations of the source placed at a depth of 100 m, within 0.5 m, and the horizontal deviations - within +-10 m. Such deviations limit the resolution of the temperature measurements at a 1 Mm path by about 5 millidegree. Thus, in the shallow water, the acoustic tracking system intended for locating the source deviation, will be an optional component of the transmitting complex.

10. In the deep water a source tracking system is a necessary component of the whole transmitting complex.

REFERENCES

1. P. N. Mikhalevsky, A. B. Baggeroer, A. N. Gavrilov, M. M Slavinsky, "Experiment Tests Use of Acoustics to Monitor temperature and Ice in Arctic Ocean", EOS, vol.76, No.27, pp.265-269, 1995

2. A. J. Plueddemann, "Internal Waves Observations from the Arctic Environment Drifting Buoys", J.Geoph.Res.,vol.97,.pp.12619-12638, 1992

3. A.N.Gavrilov, A.Yu.Lyubtchenko, Personal Communication.

4. E. C. Carmack, "personal communication"; SCICEX95 Data

5. S. V. Pisarev, "Spatial and temporal characteristics of internal waves at the edge of the continental shelf in the Arctic Basin", Oceanology, v.32, No.5, pp.579-583, 1992

6. S.V. Pisarev, "Internal Wave Measurements with Distributed Temperature Sensors near the Arctic Ocean Continental Margin",in IEEE Oceans'95 Proceedings, 1995

7. A. N. Gavrilov, F. I. Kryazhev, V. N. Kudryashov, "Numerical modelling of low-frequency sound propagation in the Arctic waveguide", J.Acoust.Soc.Am., 94(3, Pt.2), p.1770, 1993.

8. A. N. Gavrilov, V. N. Kudryashov, "Numerical modeling of low- frequency sound propagation in the horizontally stratified Arctic waveguide", AcoustInform Tech.Rep. 94/1, AcoustInform, Moscow, 1994.

9. R. H. Bourk, A. S. McLaren, "Contour mapping of Arctic basin ice draft and roughness parameters", J.Geoph.Res., 97, N.C11, pp.17,715-17,728, 1992.

10. S. V. Brestkin, et al., "Statistical characteristics of the bottom profile of the Arctic ice cover. Analysis of climatic changes of the Arctic ice extent", AcoustInform Tech.Rep. 94/3, AcoustInform, Moscow, 1994.

11. World Ocean Atlas, Arctic Ocean, edited by S.Gorshkov, (MO USSR, Moscow, 1980)

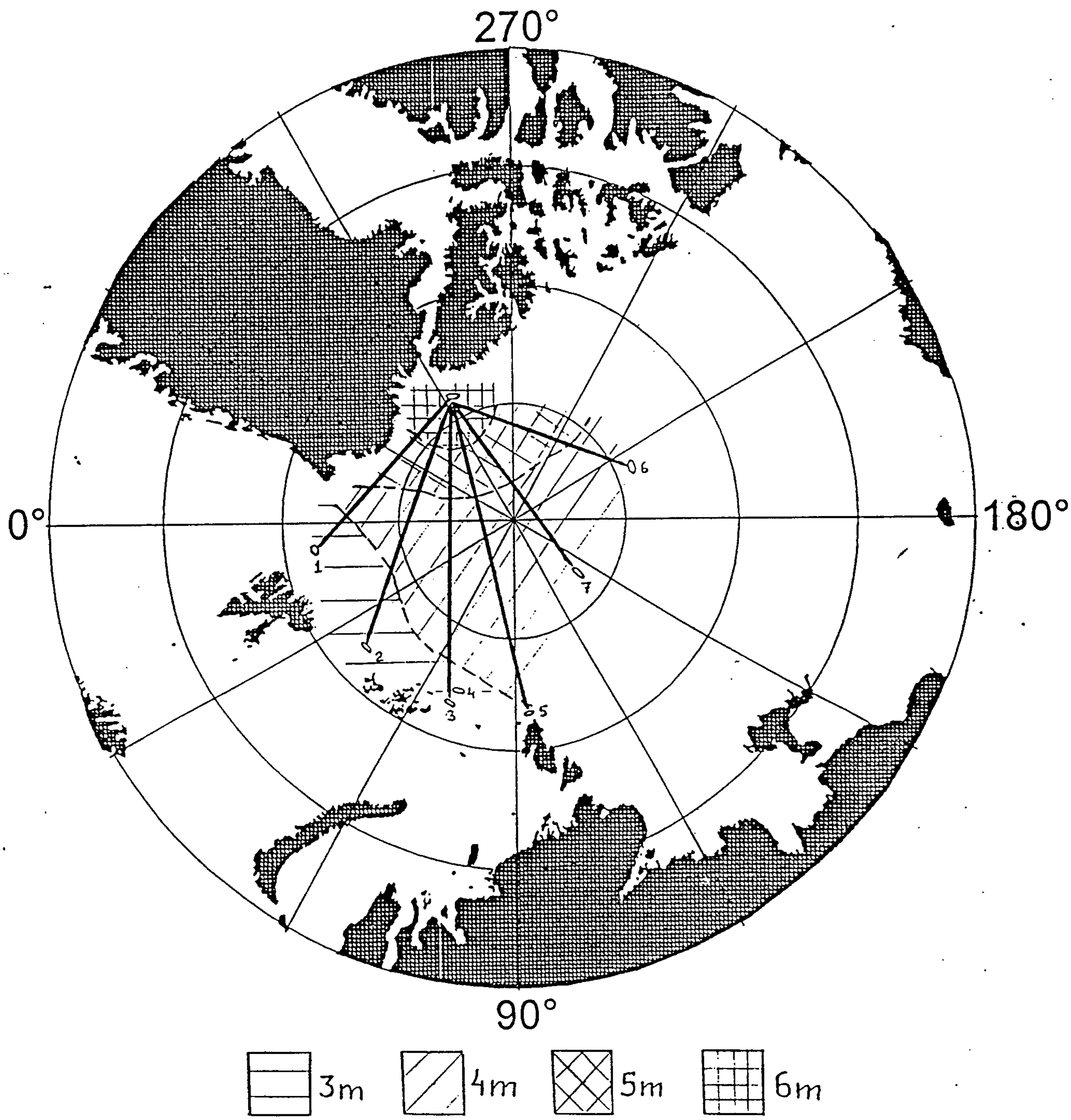

Fig.1. Scheme of the acoustic paths; contour lines define the regions of different mean ice thickness assumed for modelling.

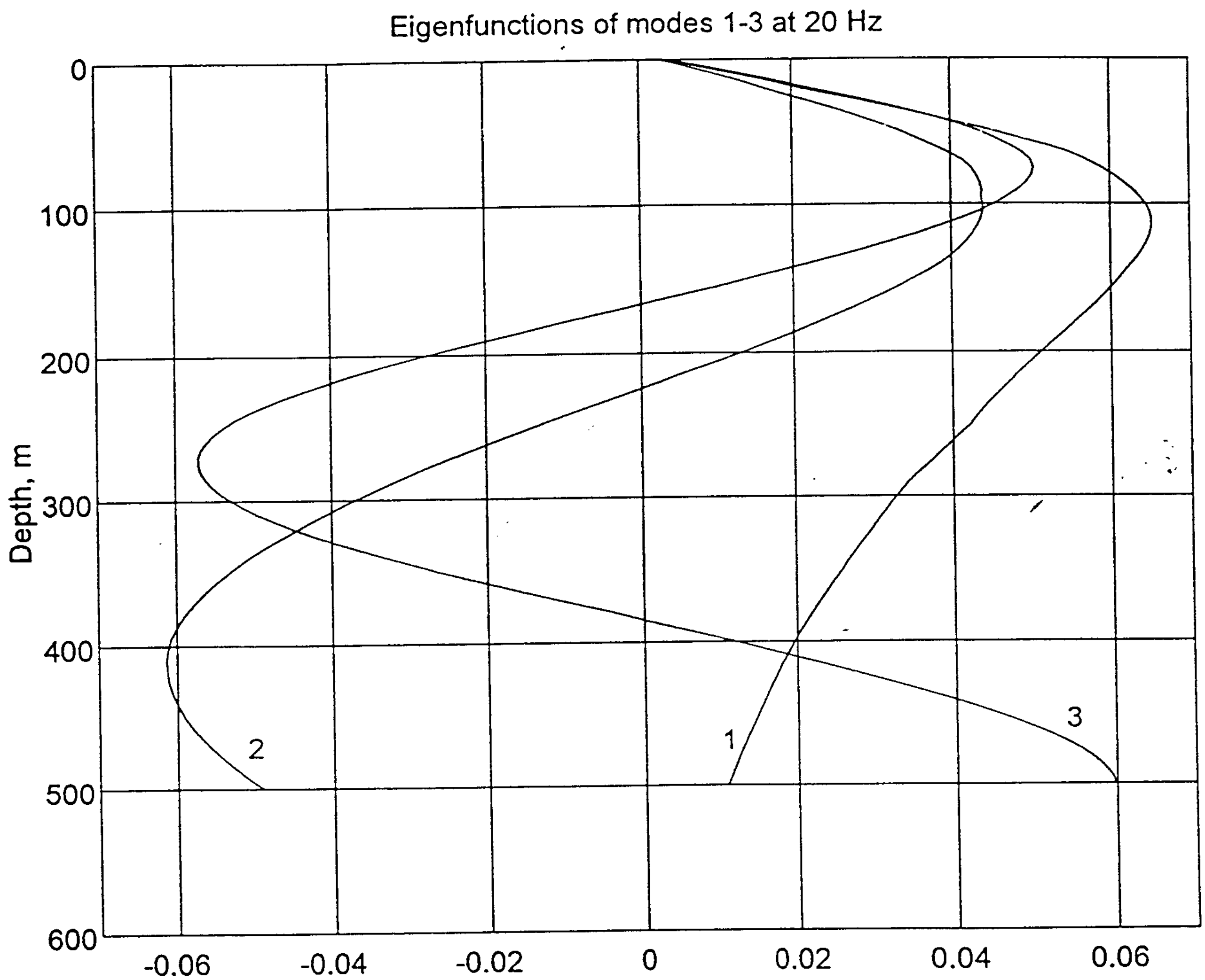

Fig.2. Eigenfunctions of modes 1-3 at 20 Hz calculated for a typical sound speed profile in the St. Anna Strait.

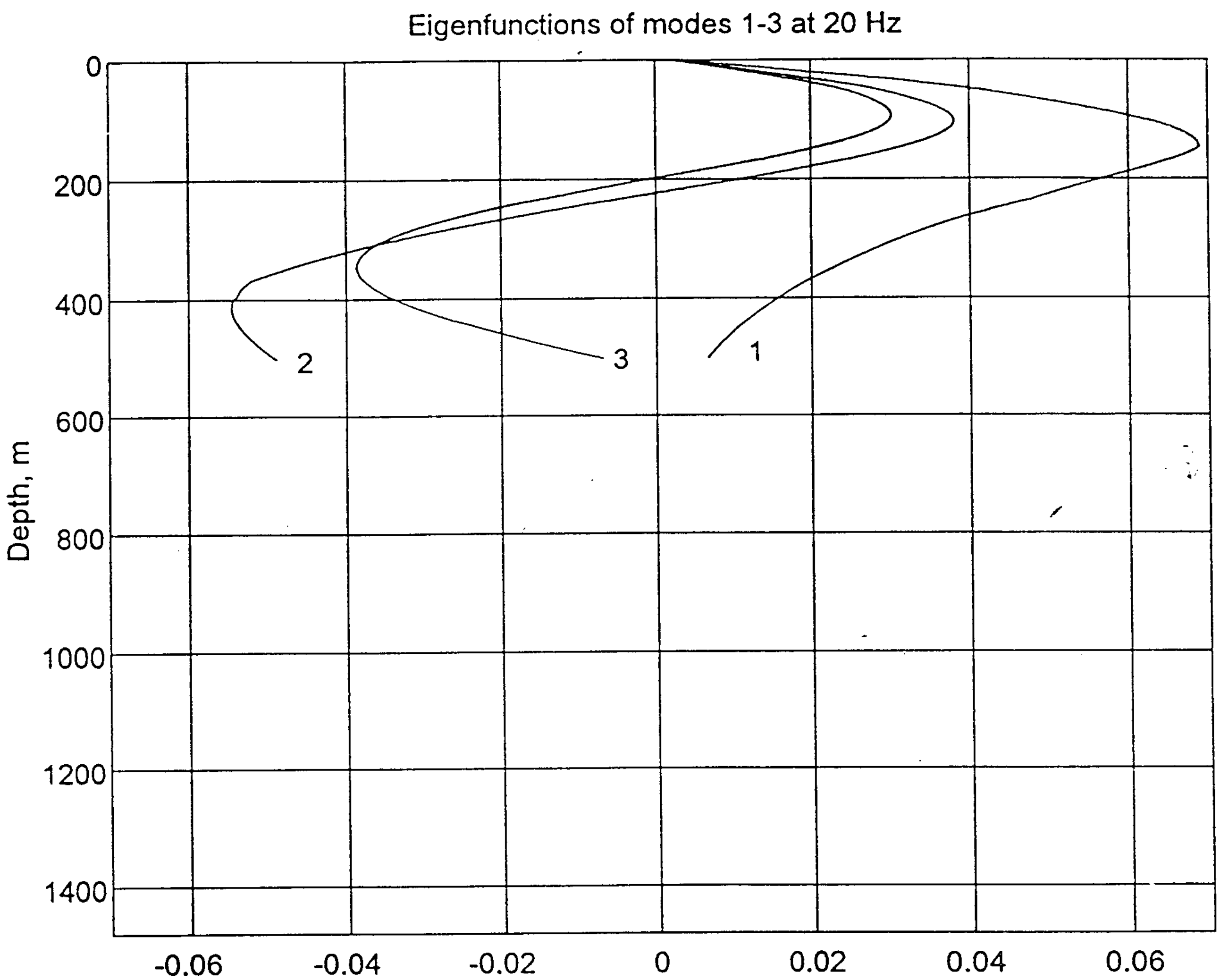

Fig.3. Eigenfunctions of modes 1-3 at 20 Hz calculated for a typical sound speed profile at the Alpha Ridge.

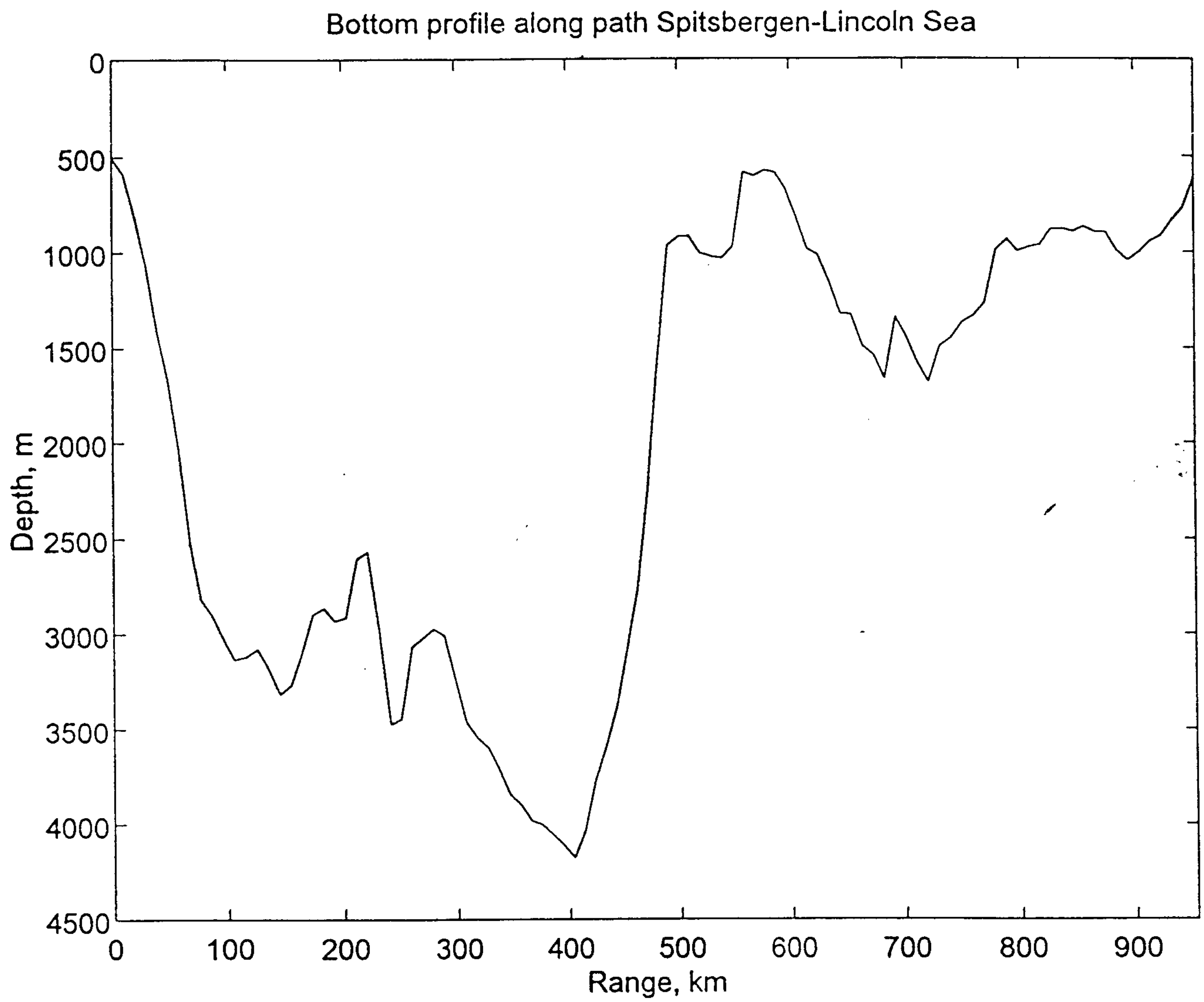

Fig.4. Bottom profile along the Spitsbergen - Lincoln Sea path. (1)

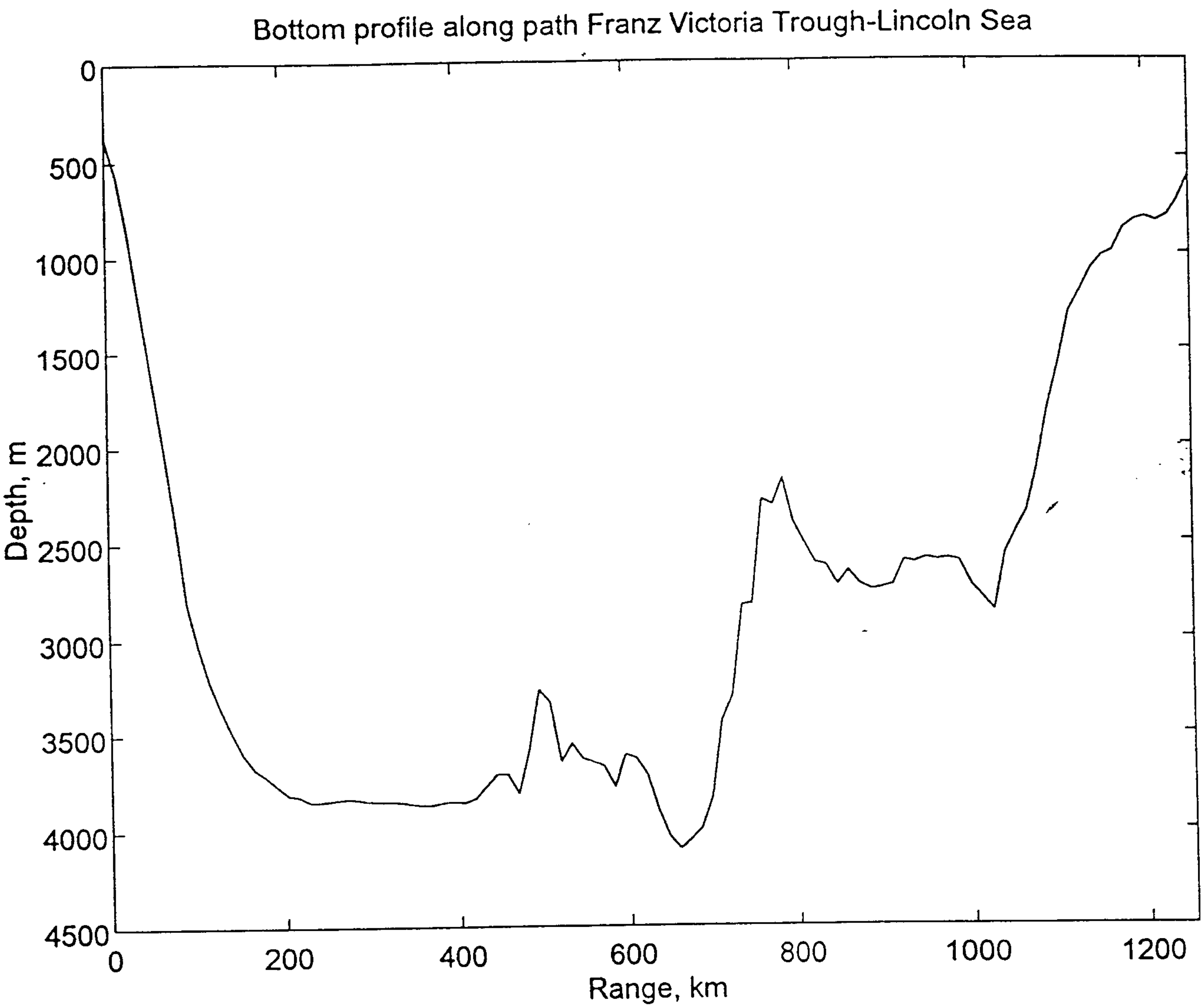

Fig.5. Bottom profile along the Franz Victoria Strait - Lincoln Sea path. (2)

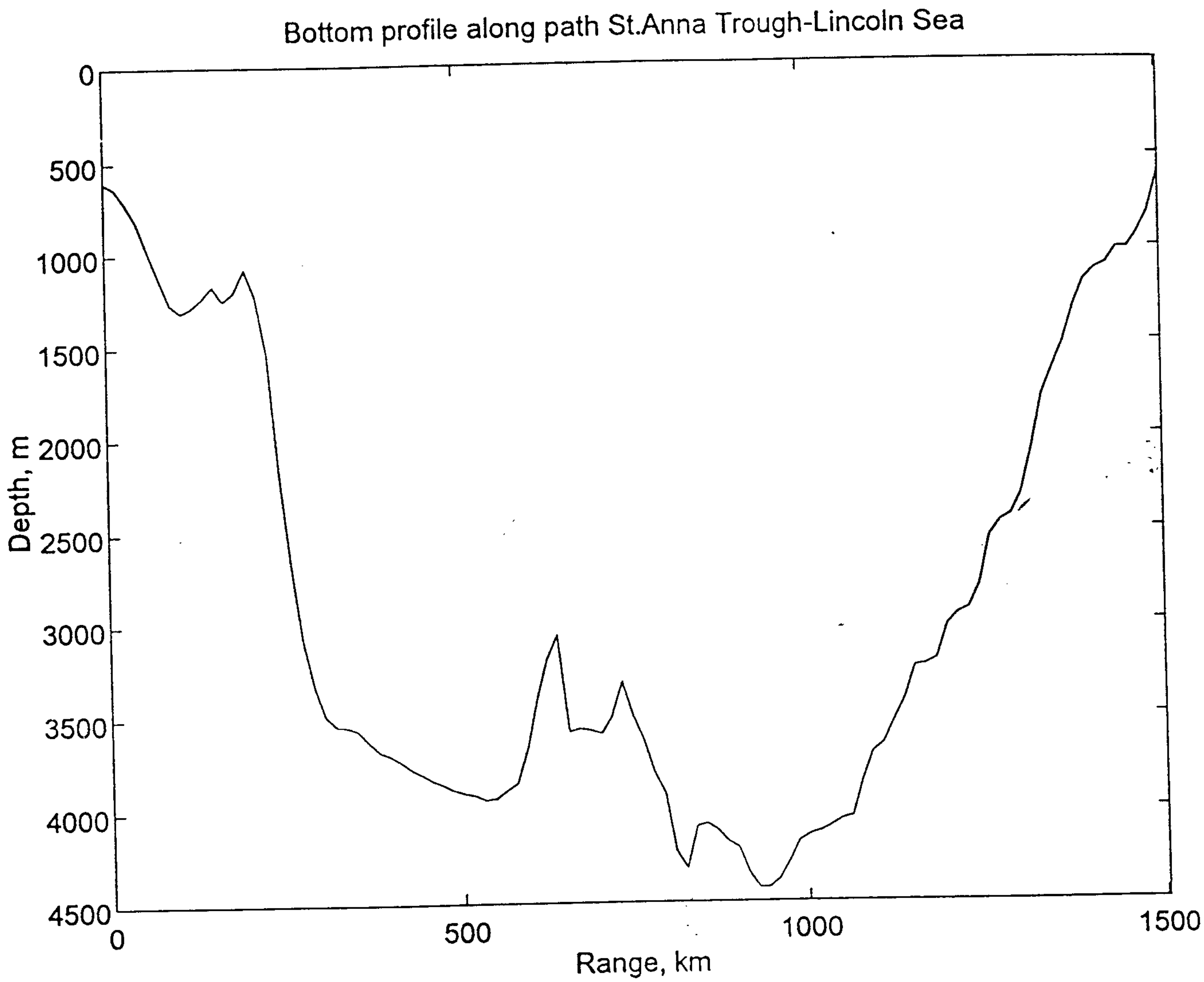

Fig.6. Bottom profile along the St. Anna Strait - Lincoln Sea path. (3)

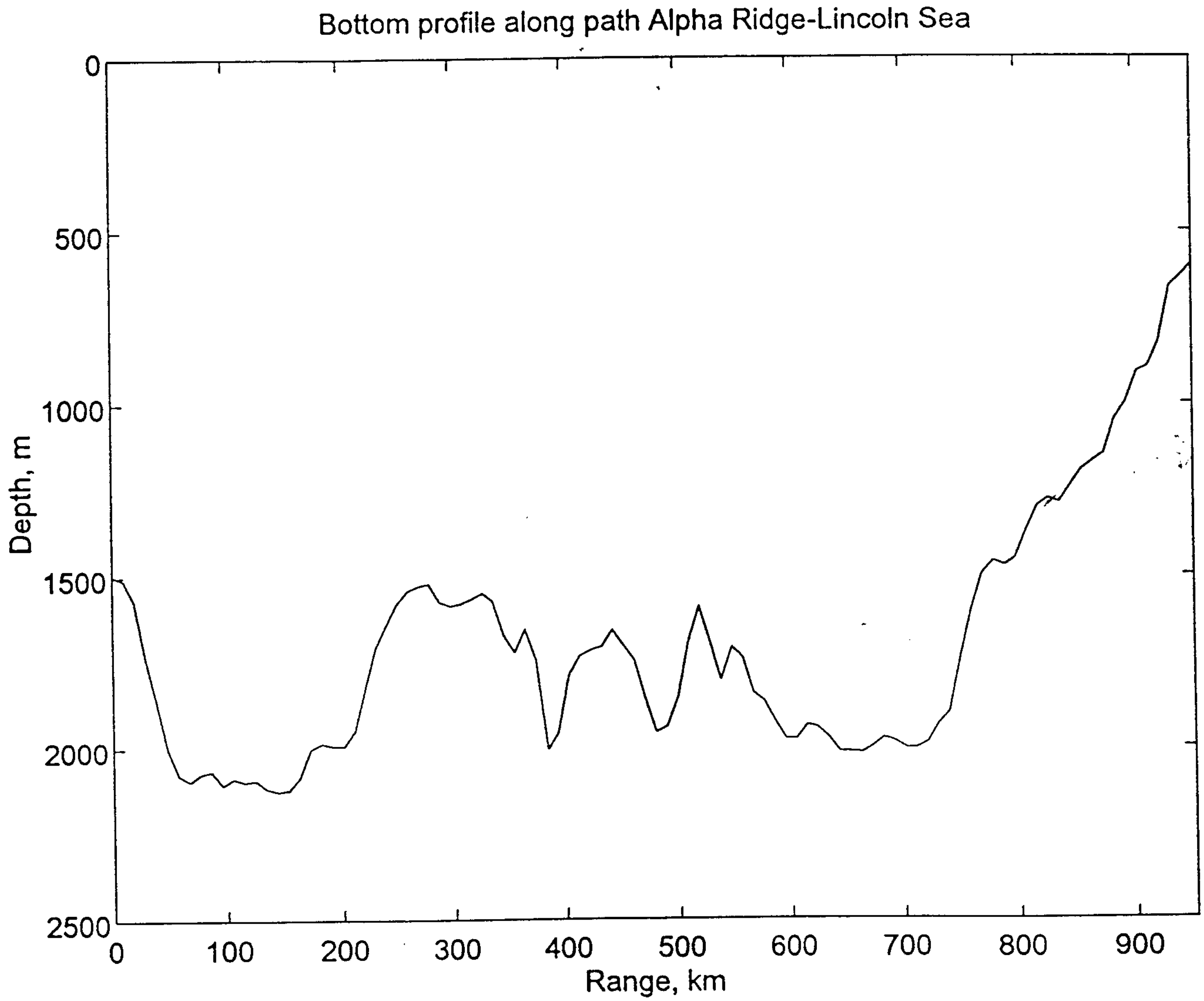

Fig.7. Bottom profile along the Alpha Ridge - Lincoln Sea path. (6)

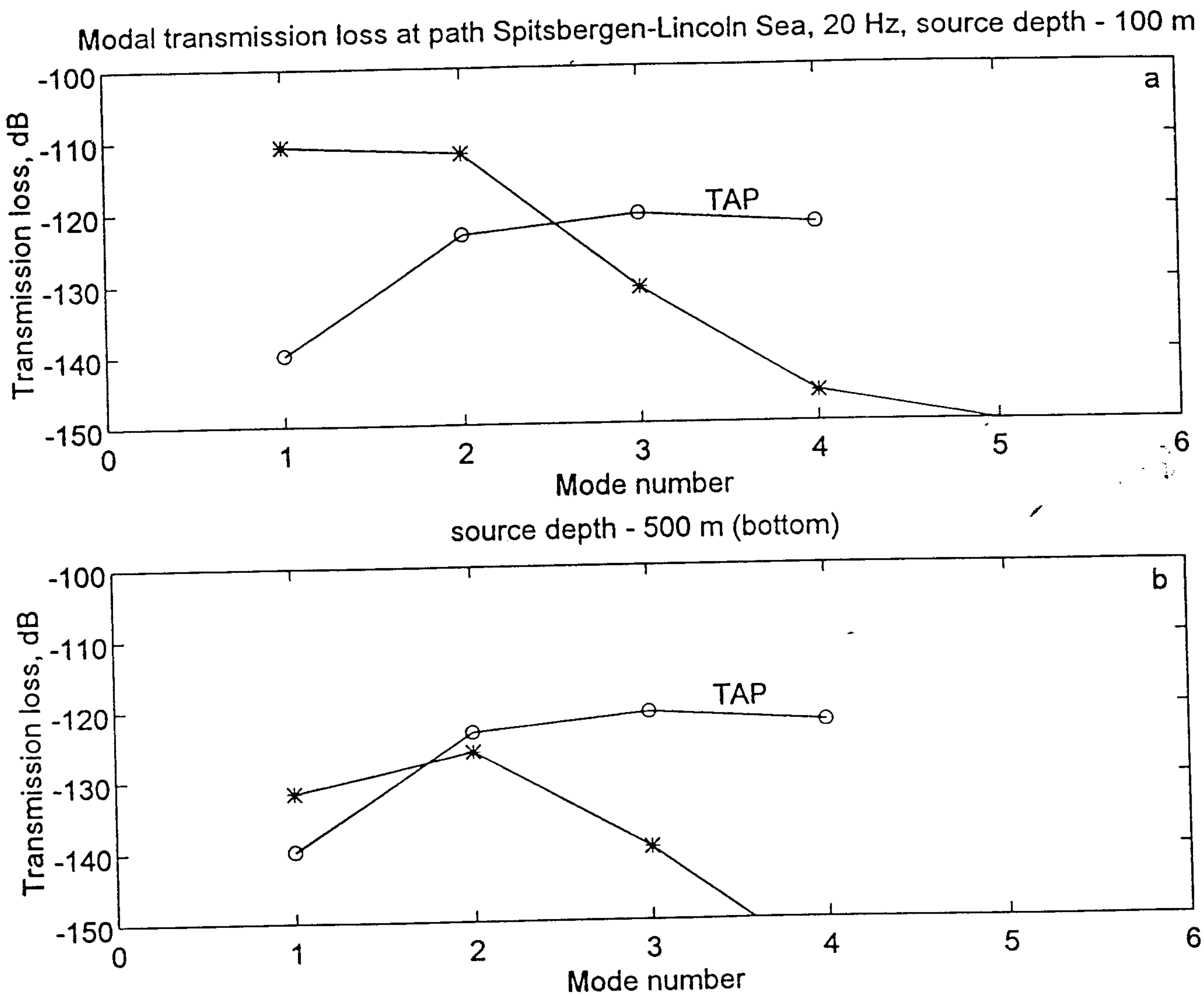

Fig.8. Modal transmission loss at path 1, at 20 Hz, for a source depth of 100 m (a), and 500 m (b); circles show the TAP experiment results on modal transmission loss in the signals received at the ice camp "SIMI".

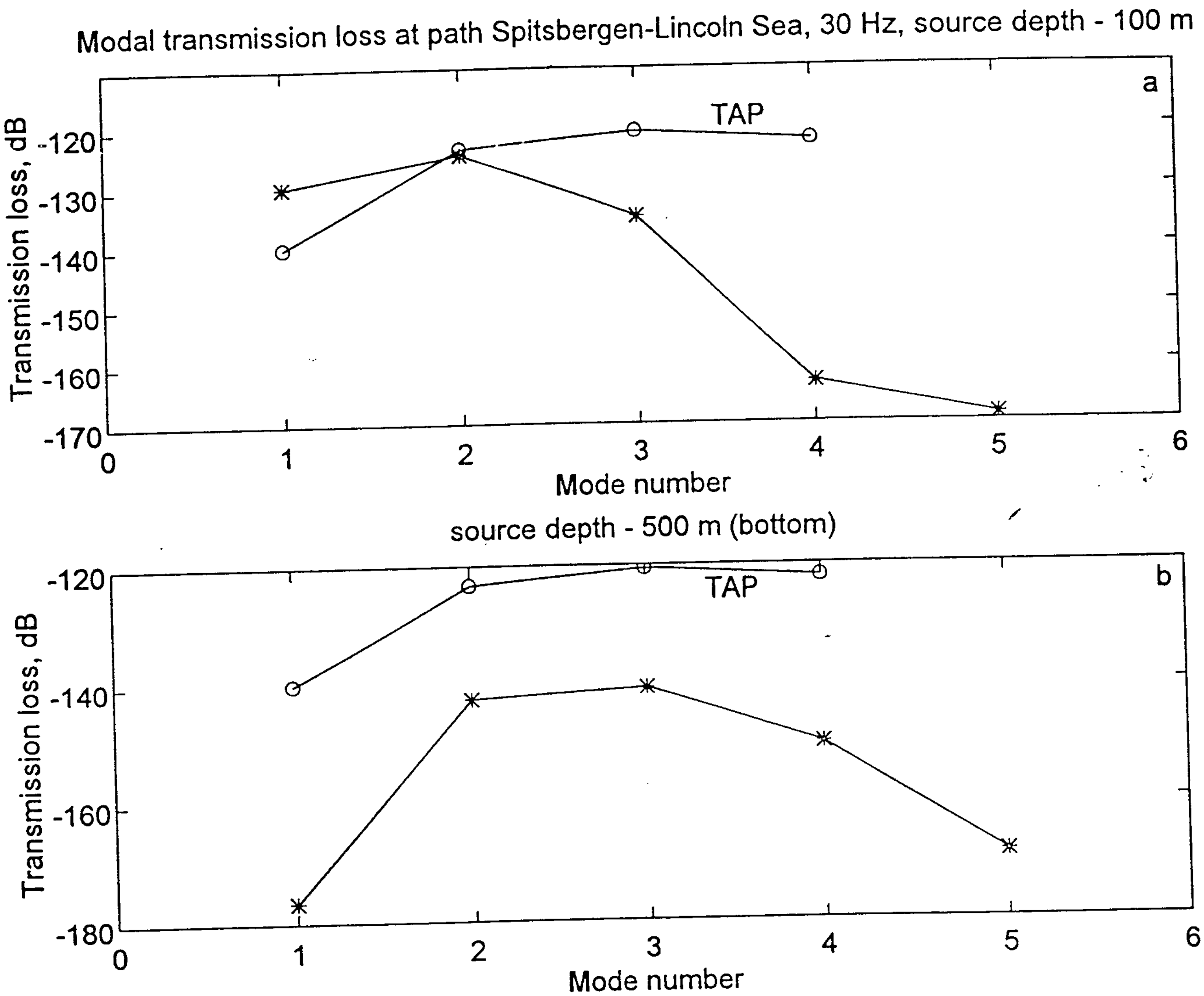

Fig.9. Modal transmission loss at path 1, at 30 Hz, for a source depth of 100 m (a), and 500 m (b).

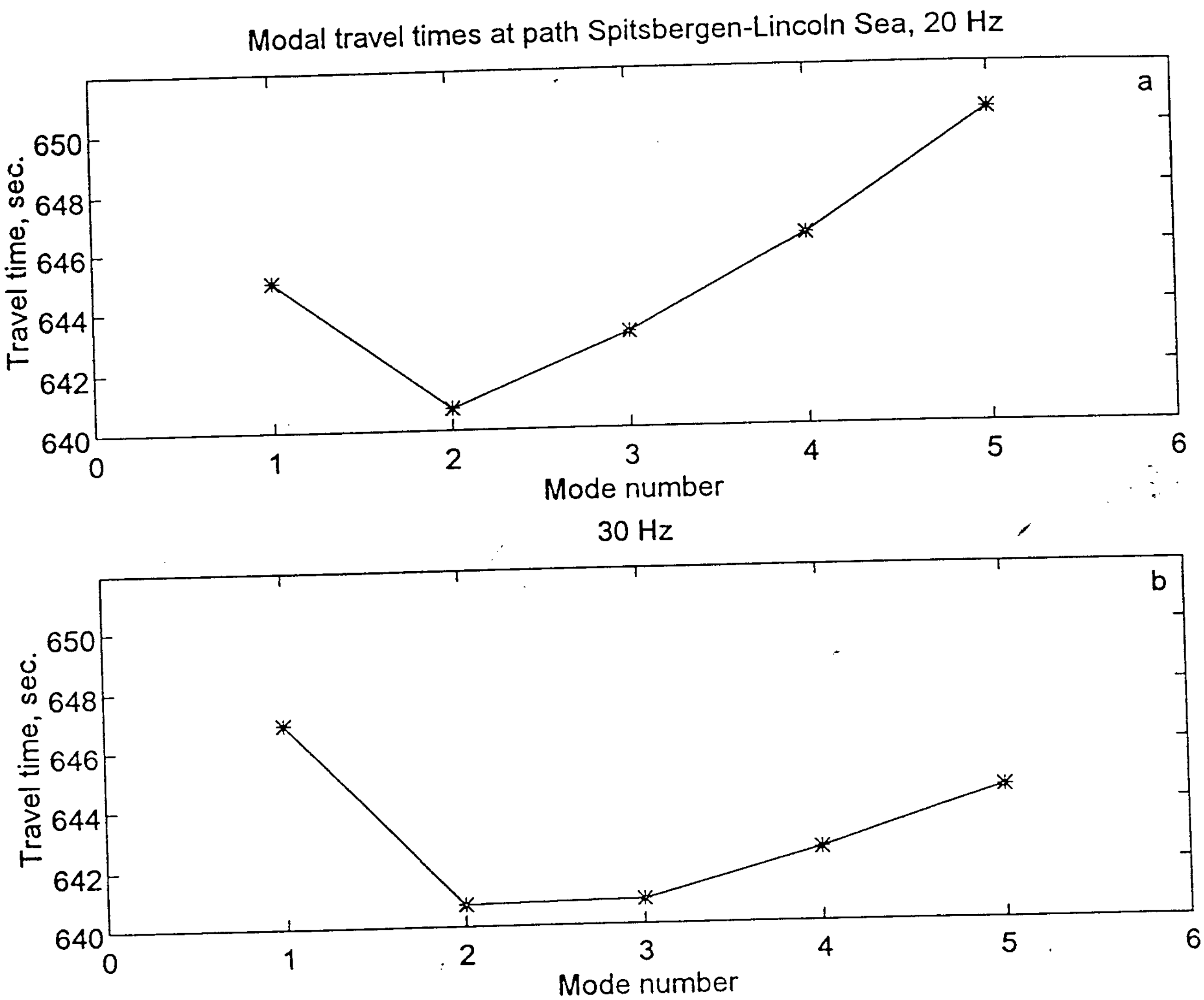

Fig.10. Modal travel times at path 1.

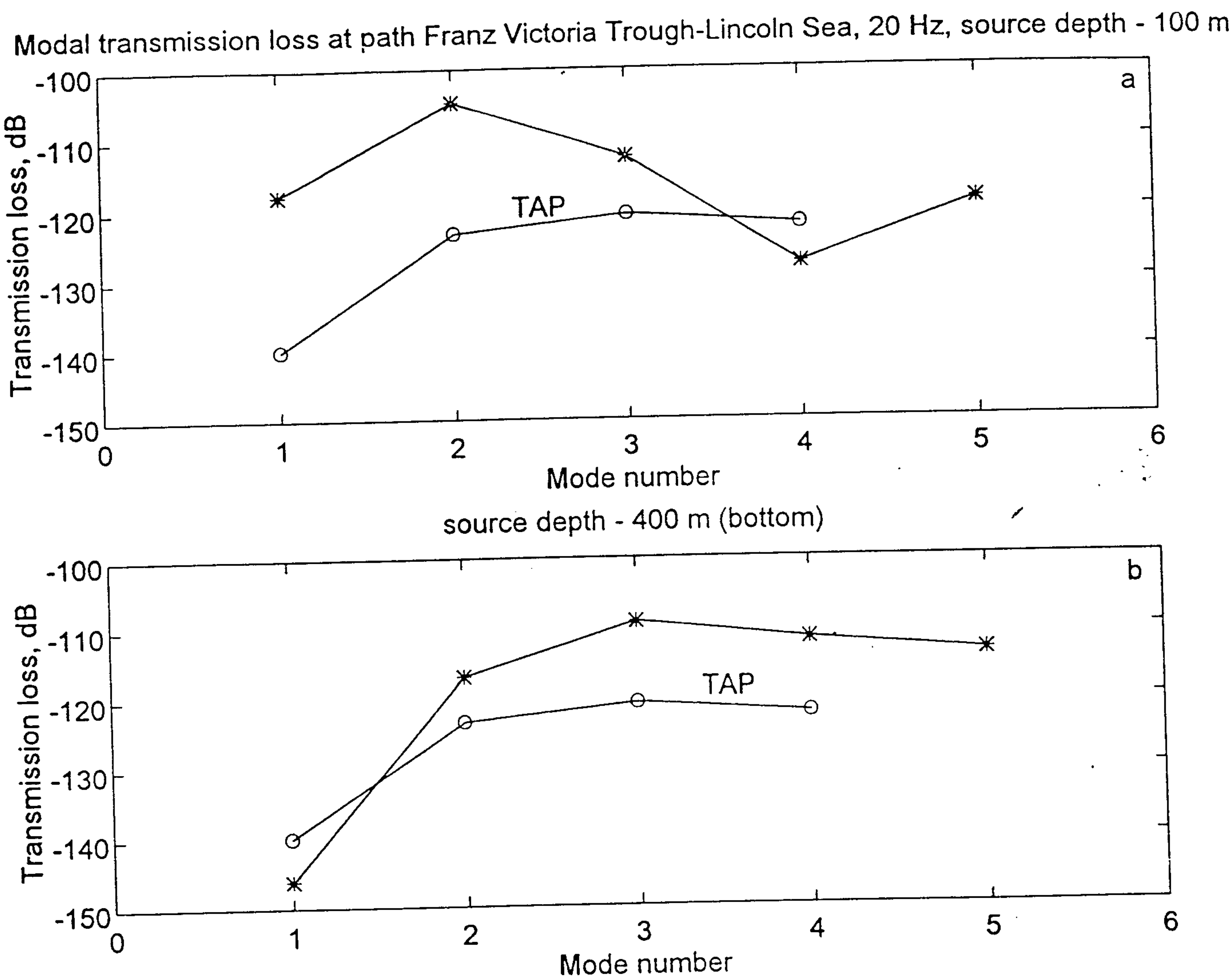

Fig.11. Modal transmission loss at path 2, at 20 Hz, for a source depth of 100 m (a), and 400 m (b).

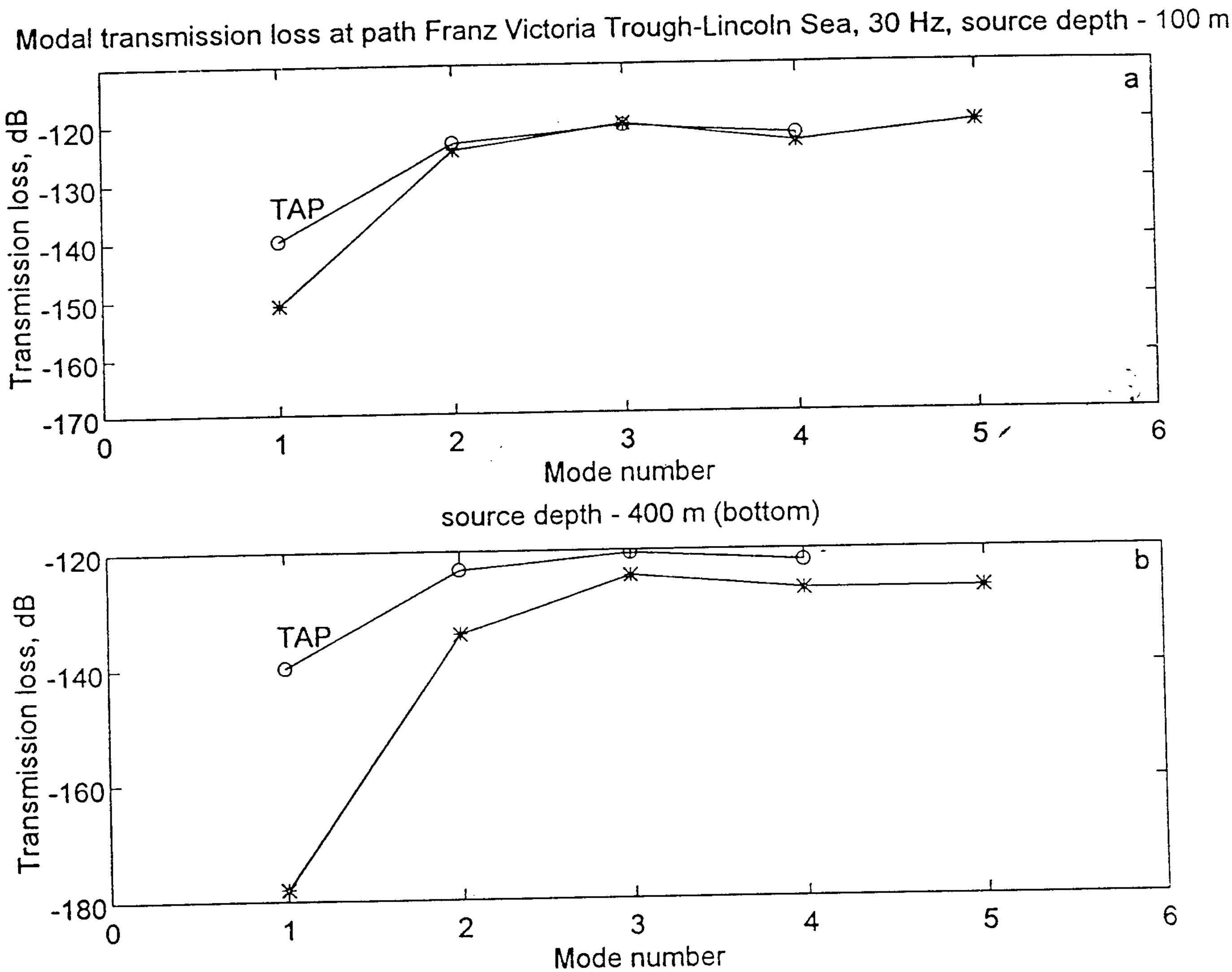

Fig.12. Modal transmission loss at path 2, at 30 Hz, for a source depth of 100 m (a), and 400 m (b).

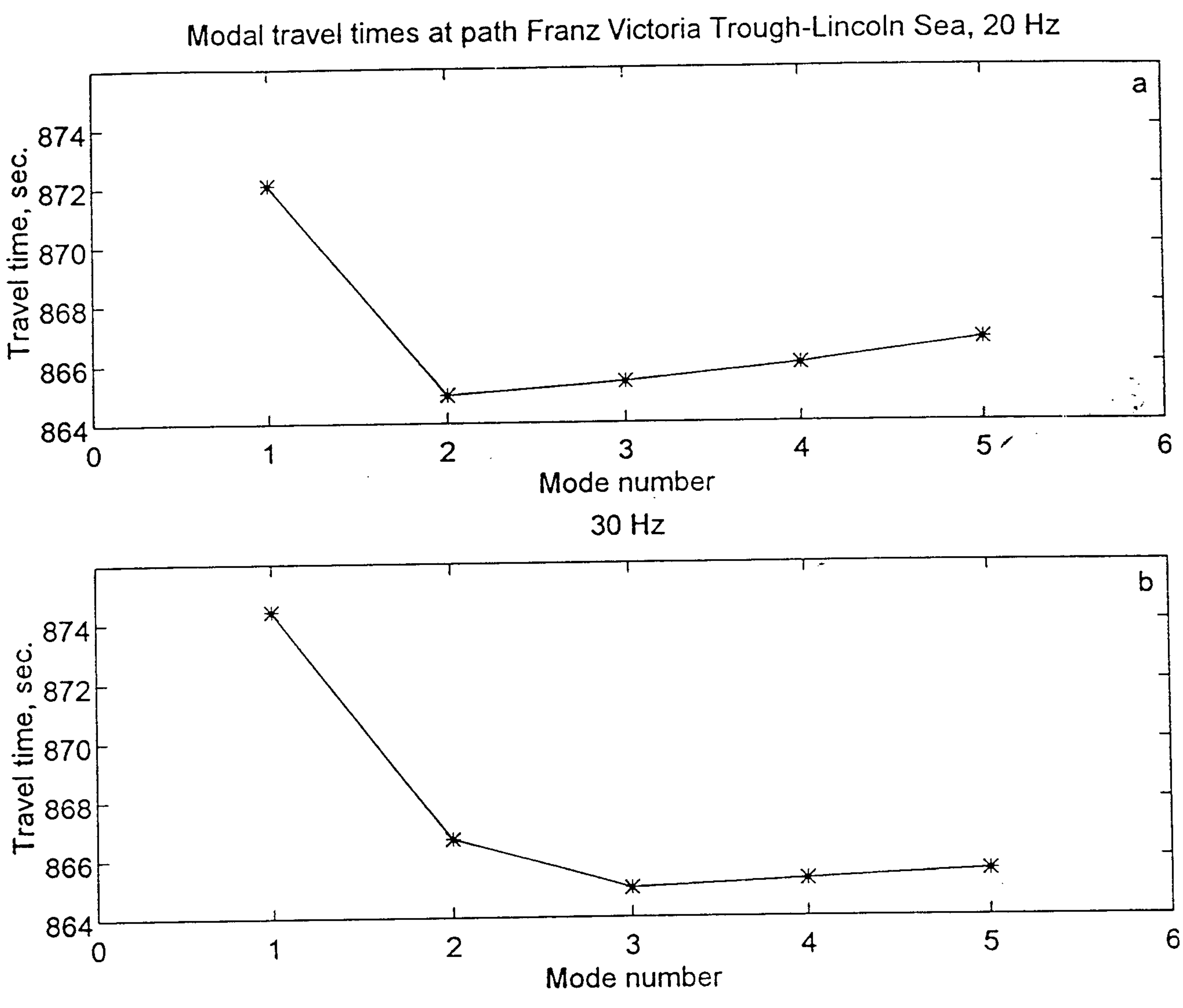

Fig.13. Modal travel times at path 2.

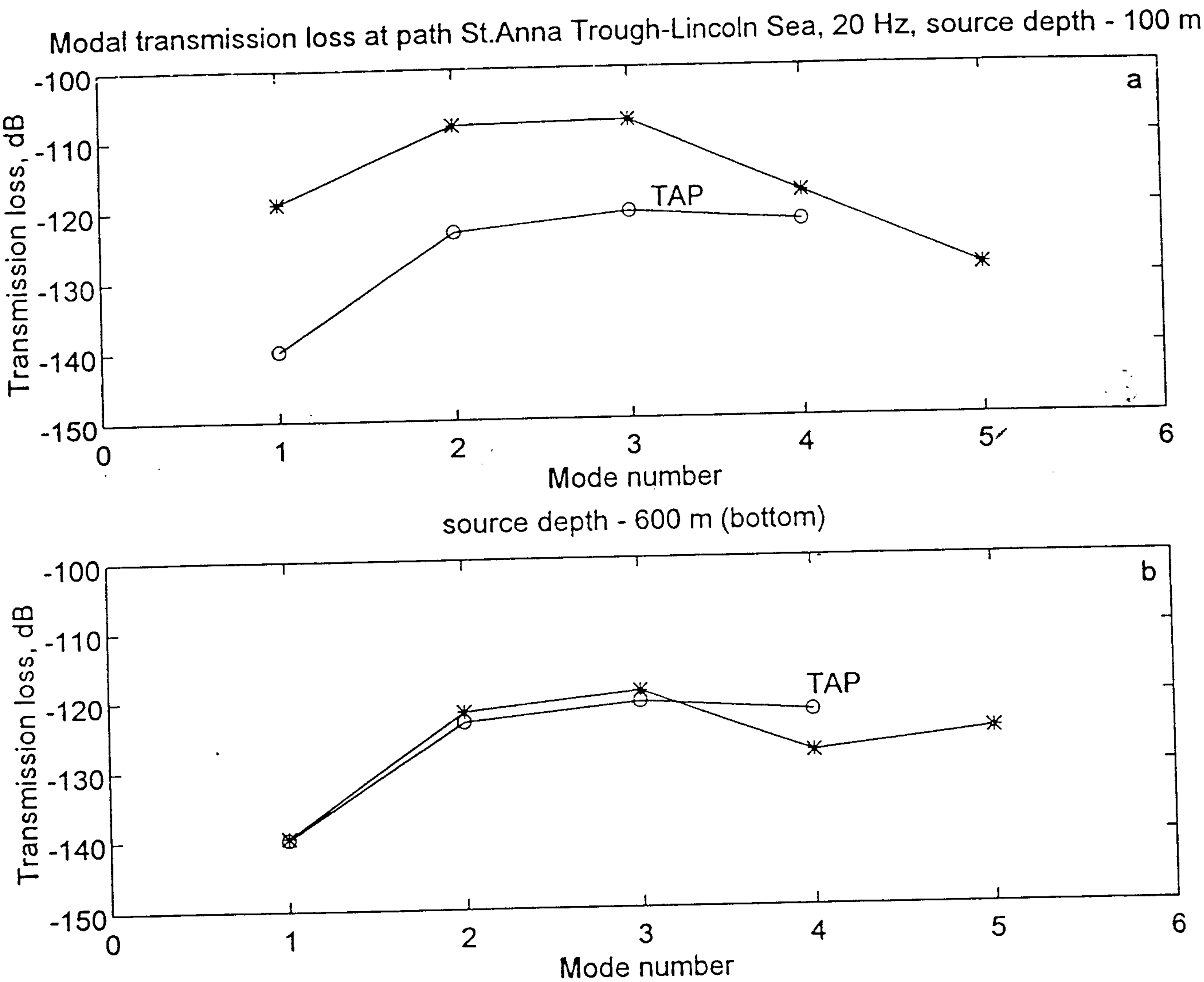

Fig.14. Modal transmission loss at path 3, at 20 Hz, for a source depth of 100 m (a), and 600 m (b).

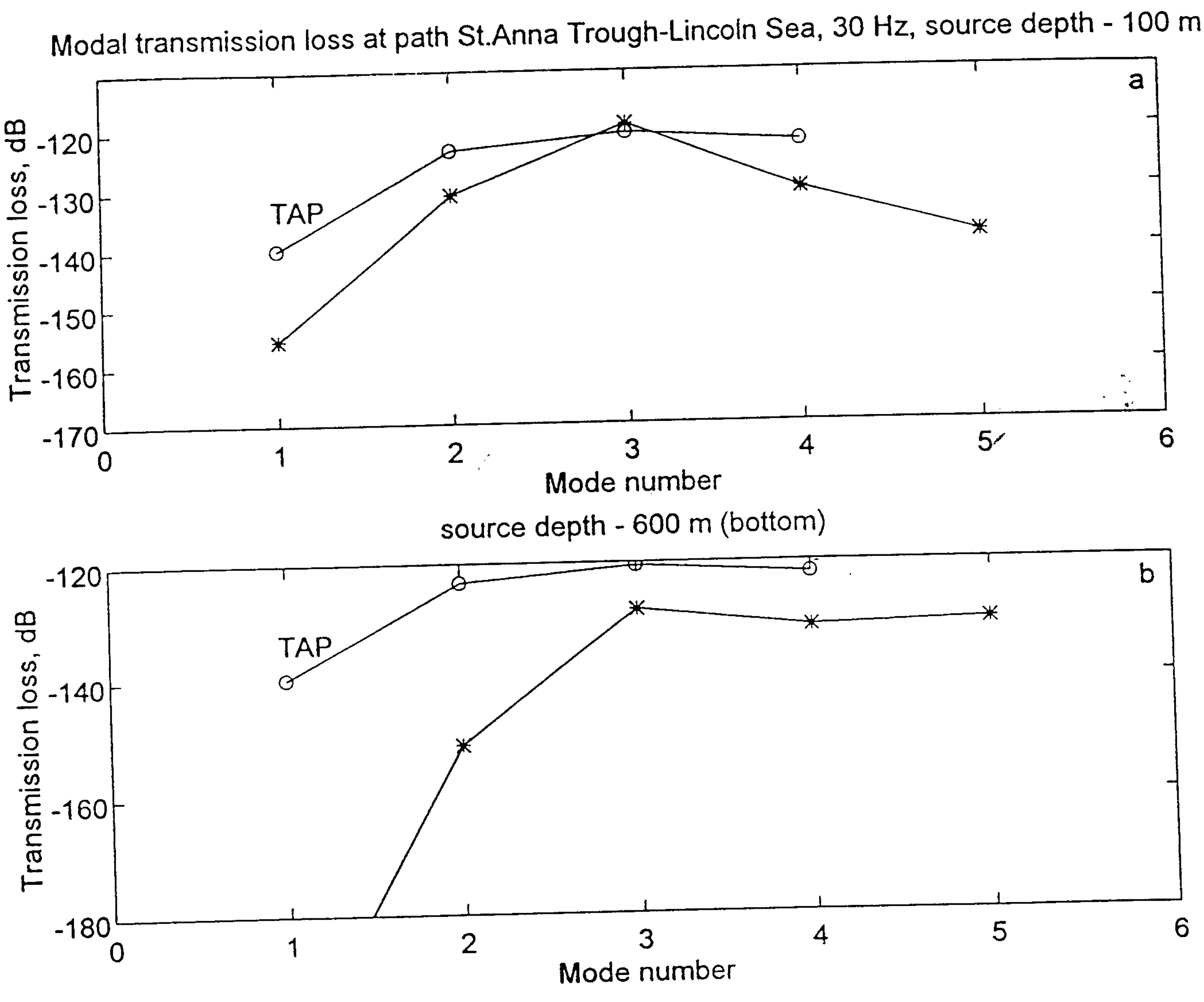

Fig.15. Modal transmission loss at path 3, at 30 Hz, for a source depth of 100 m (a), and 600 m (b).

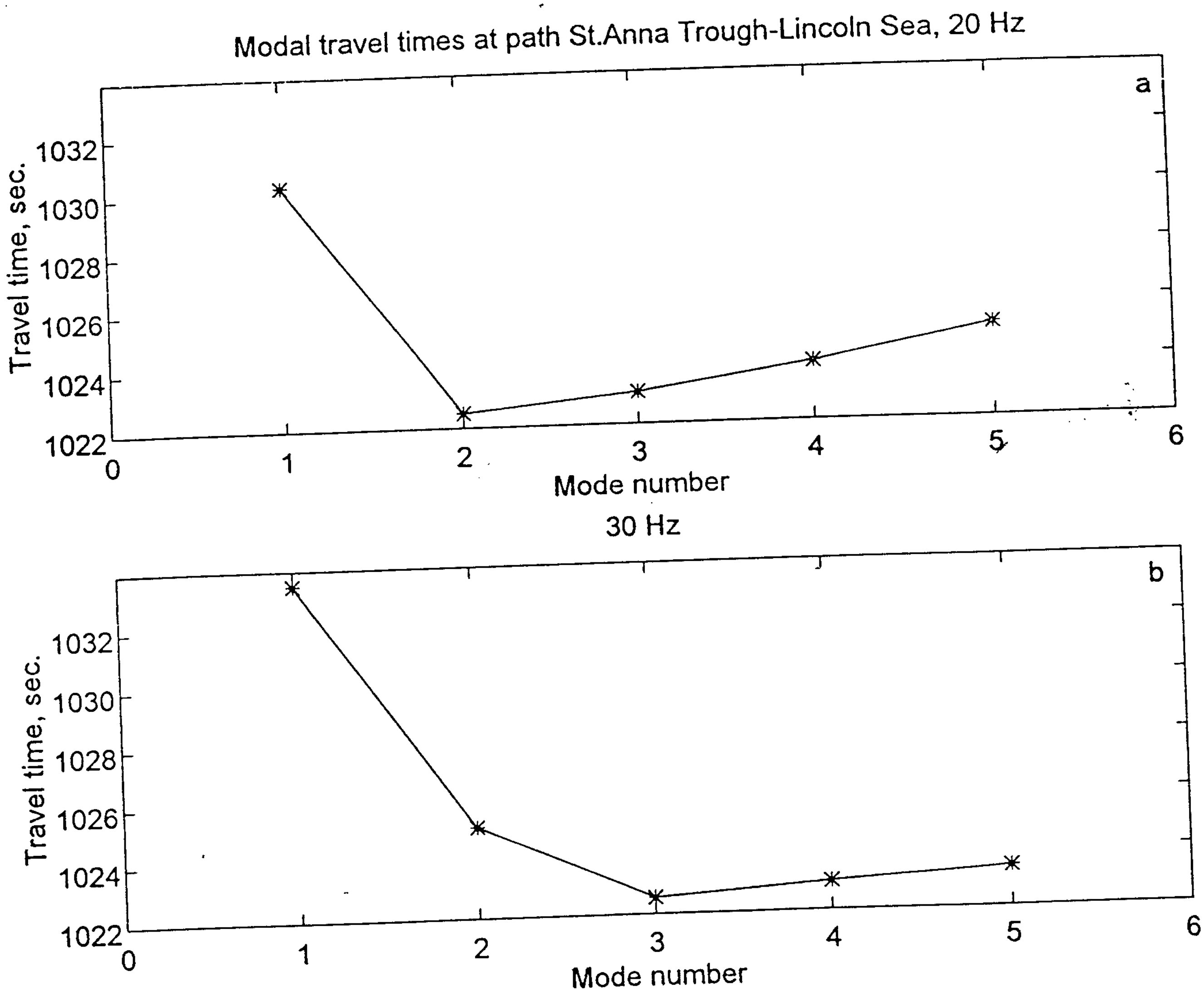

Fig.16. Modal travel times at path 3.

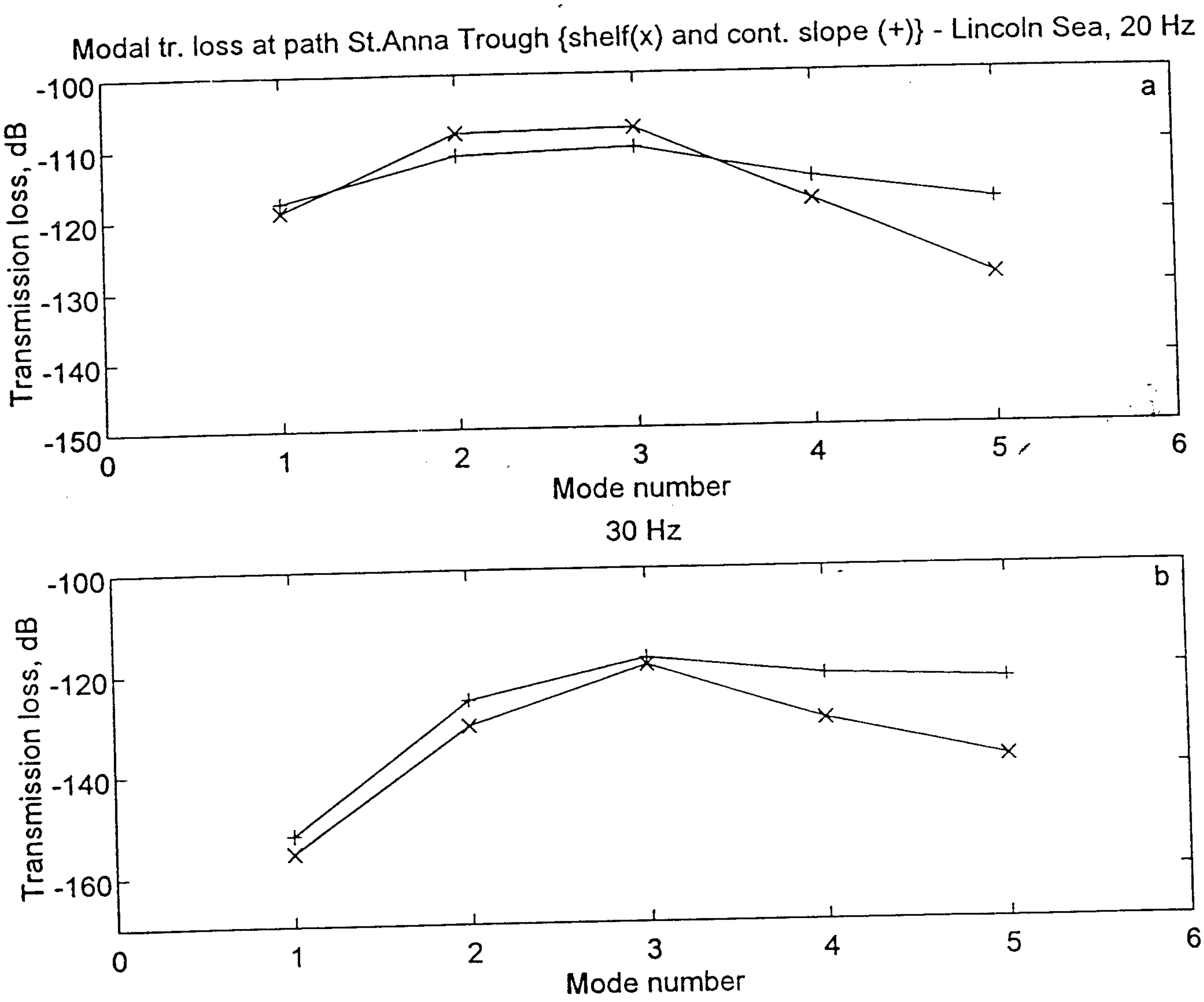

Fig.17. Comparison of the modal transmission loss at paths 3 and 4 at 20 Hz (a), and at 30 Hz (b), source depth - 100 m.

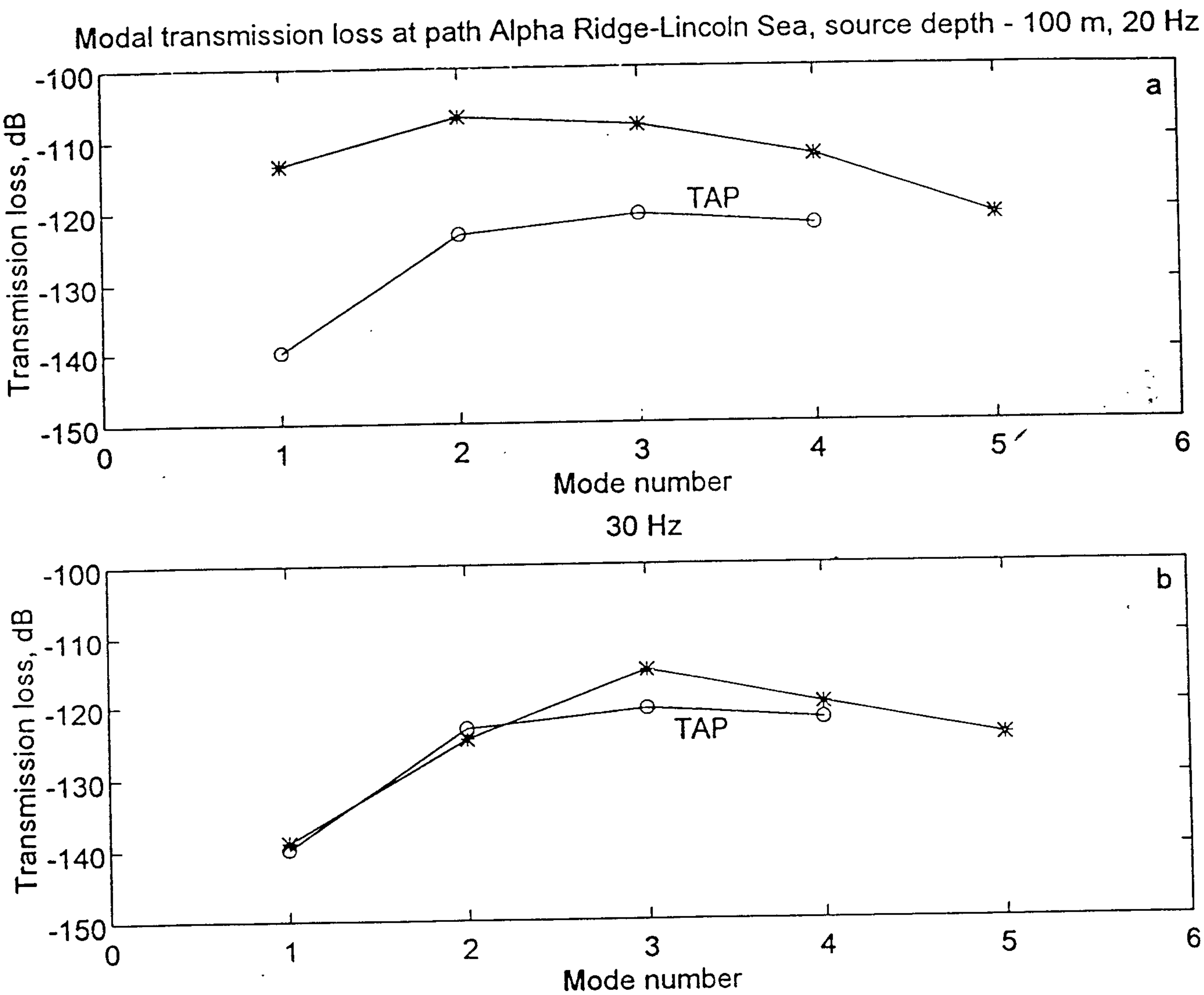

Fig.18. Modal transmission loss at path 6, at 20 Hz (a), and at 0 Hz, source depth: 100 m.

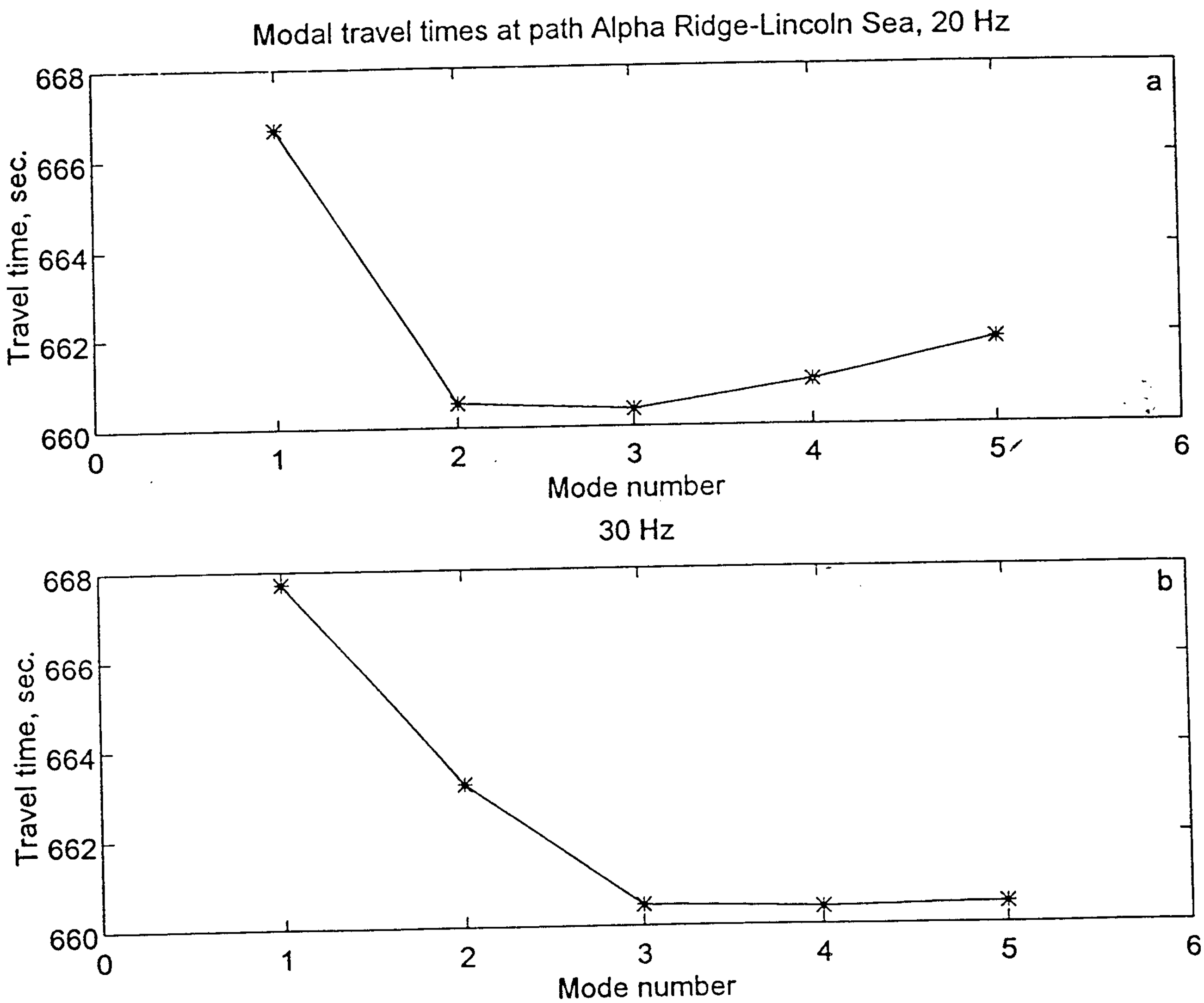

Fig.19. Modal travel times at path 6.

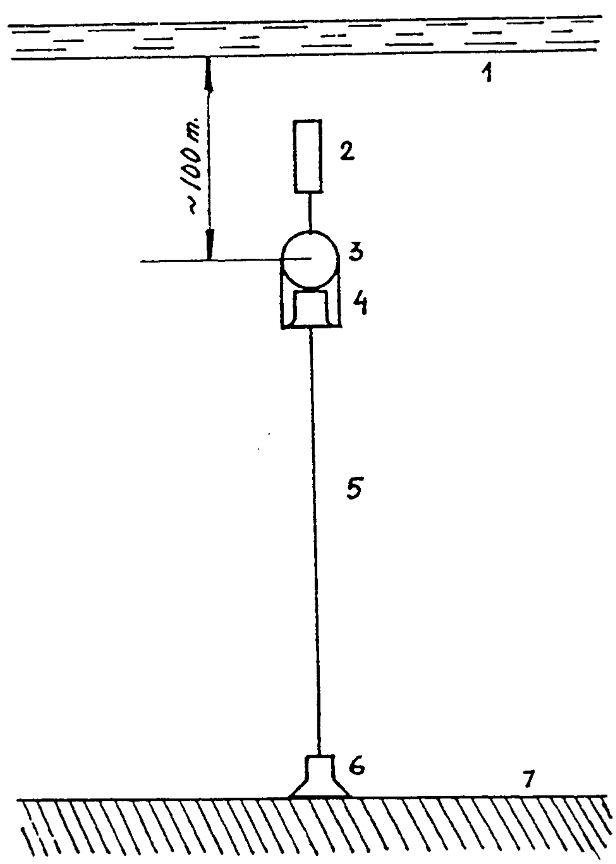

Fig.20. The general scheme of the mooring system with an autonomous source: 1 - ice cover; 2 - apex float; 3 - acoustic source; 4 - batteries and controlling unit; 5 - kevlar rope; 6 - anchor; 7 - bottom.

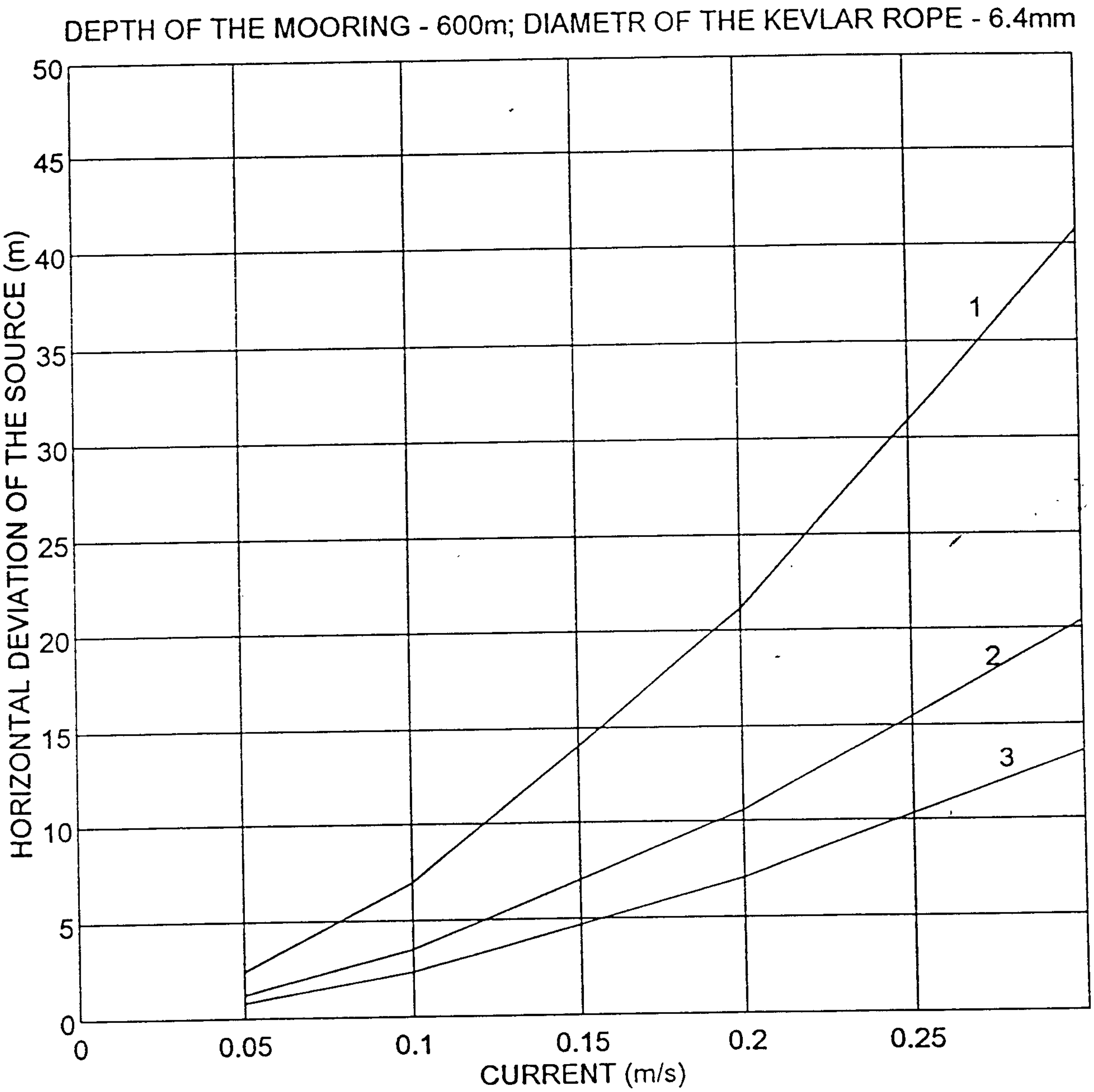

Fig.21. The horizontal deviation of the source versus current velocity in shallow water, with rope diameter - 6.4 mm, rope length - 500 m, and rope tension: 1 - 5000 N, 2 - 10000 N, 3 - 15000 N.

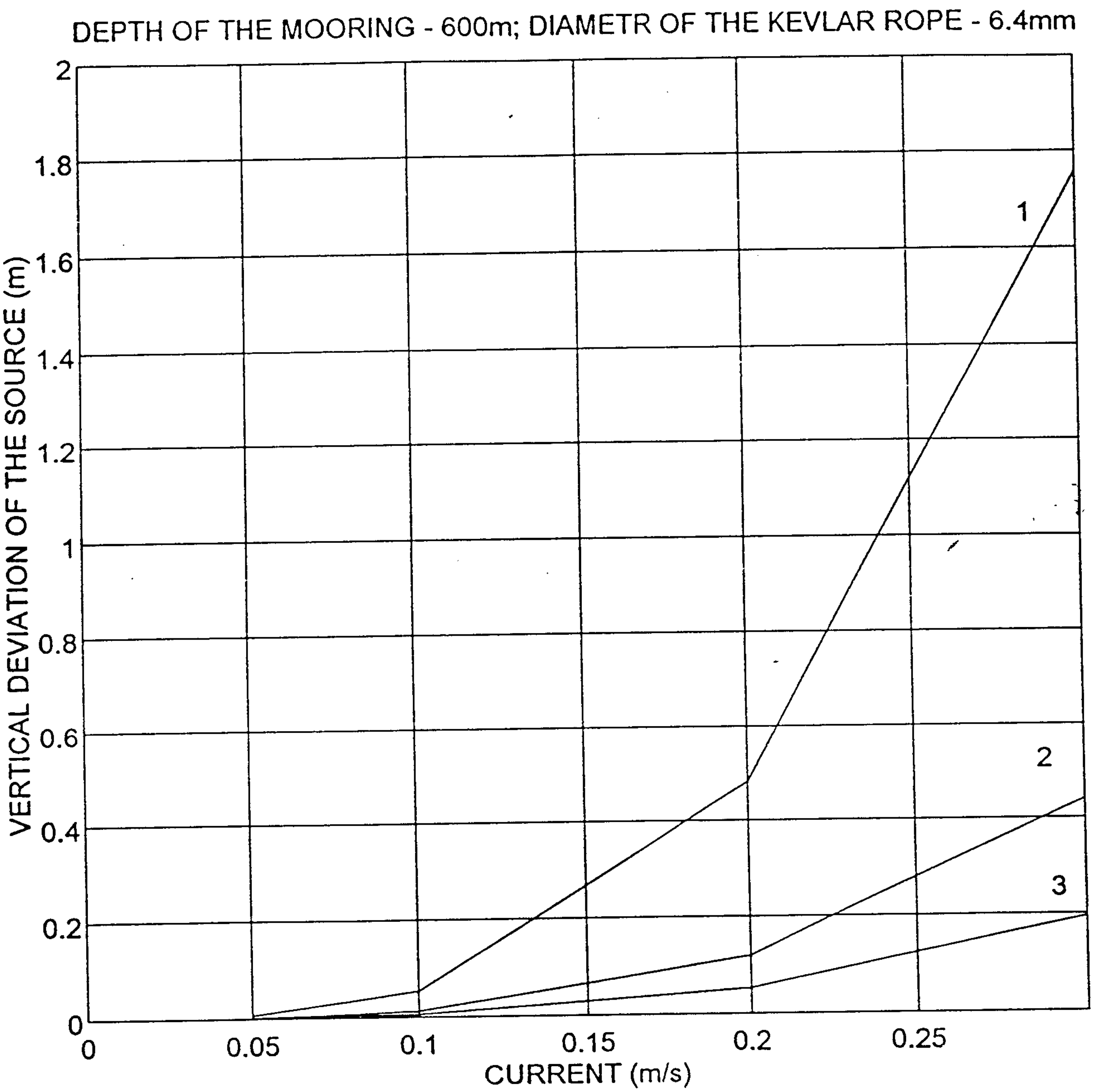

Fig.22. The vertical deviation of the source versus current velocity in shallow water, with rope diameter - 6.4 mm, rope length - 500 m, and rope tension: 1 - 5000 N,2 - 10000 N, 3 - 15000 N.

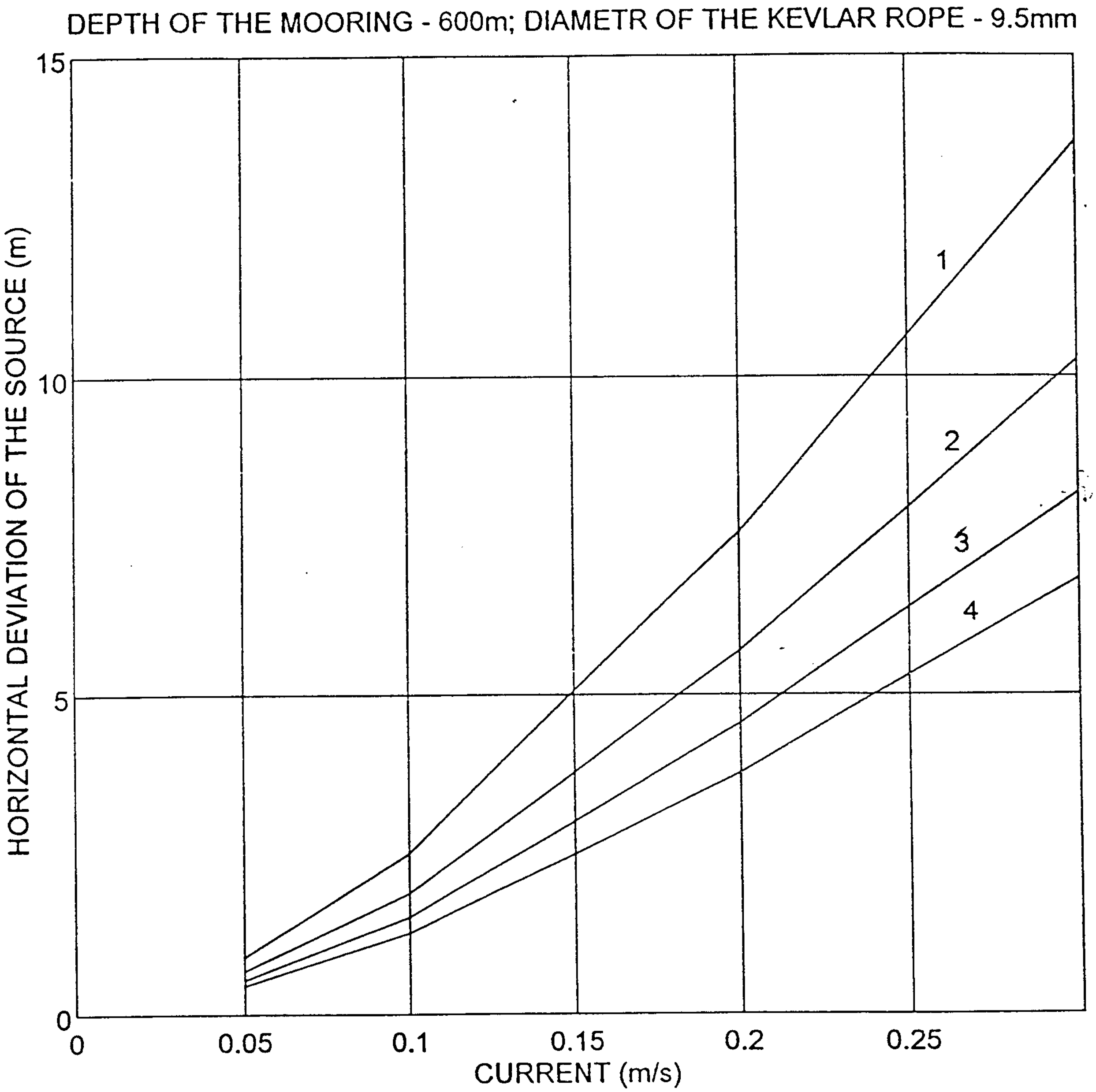

Fig.23. The horizontal deviation of the source versus current velocity shallow water, with rope diameter - 9.5 mm, rope length - 500 m, and rope tension: 1 - 15000 N, 2 - 20000 N, 3 - 25000 N, 4 - 30000 N.

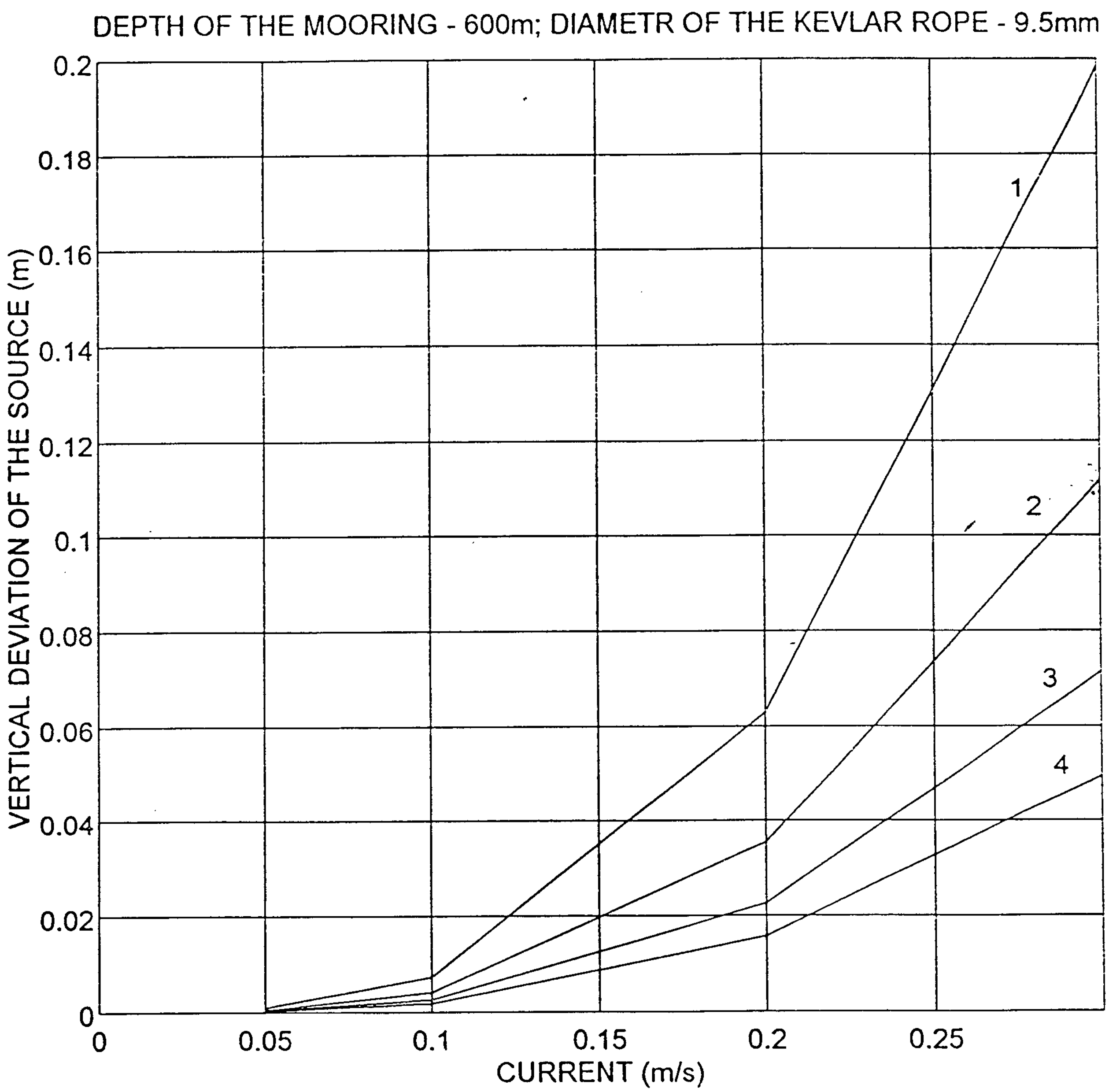

Fig.24. The vertical deviation of the source versus current velocity in shallow water, with rope diameter - 9.5 mm, rope length - 500 m, and rope tension: 1 -15000 N, 2-20000 N, 3-25000 N, 4-30000 N.

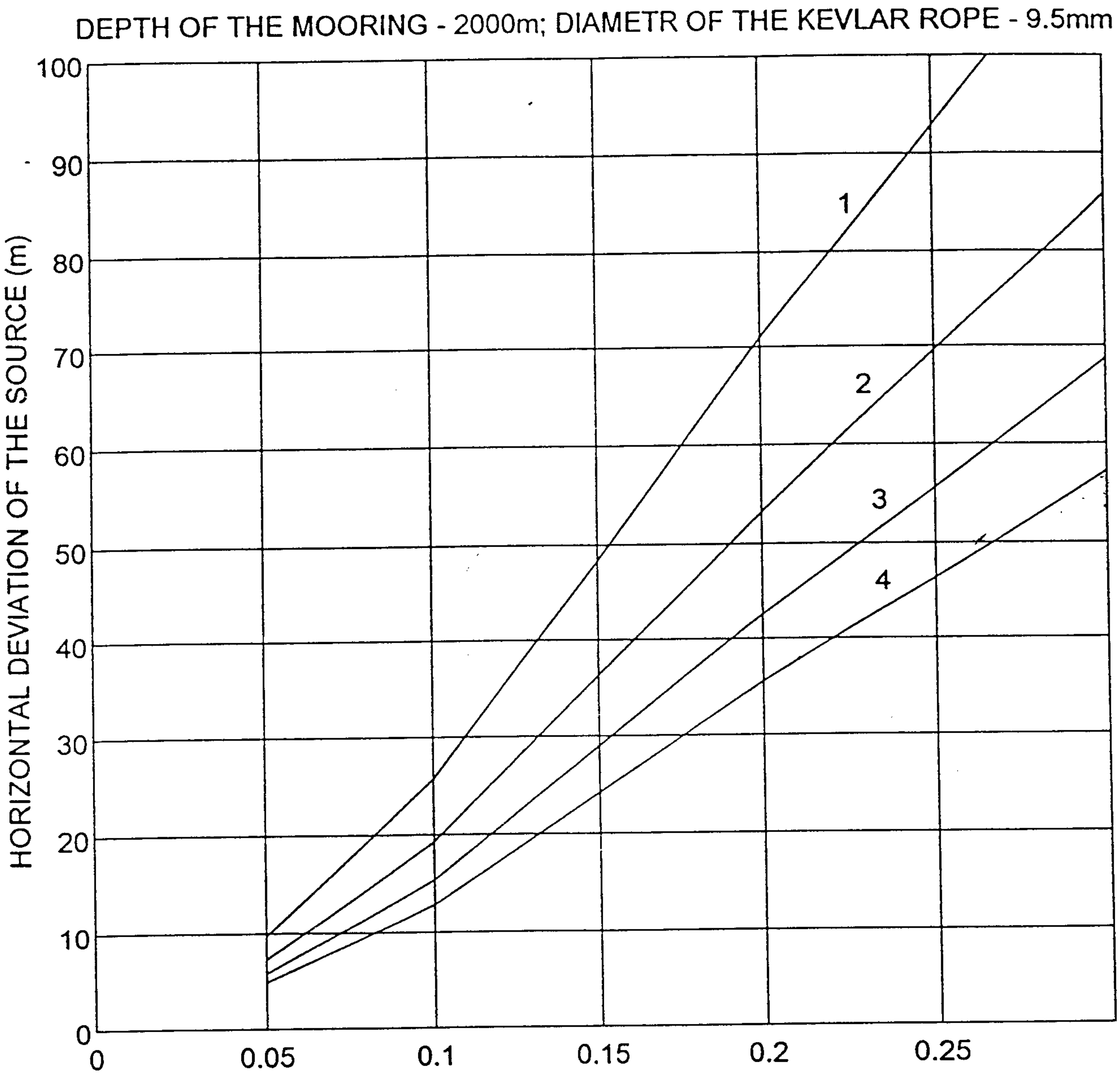

Fig.25. The horizontal deviation of the source versus current velocity in deep water, with rope diameter - 9.5 mm, rope length - 500 m, and rope tension:
1 - 15000 N, 2 - 20000 N, 3 - 25000 N, 4 - 30000 N.

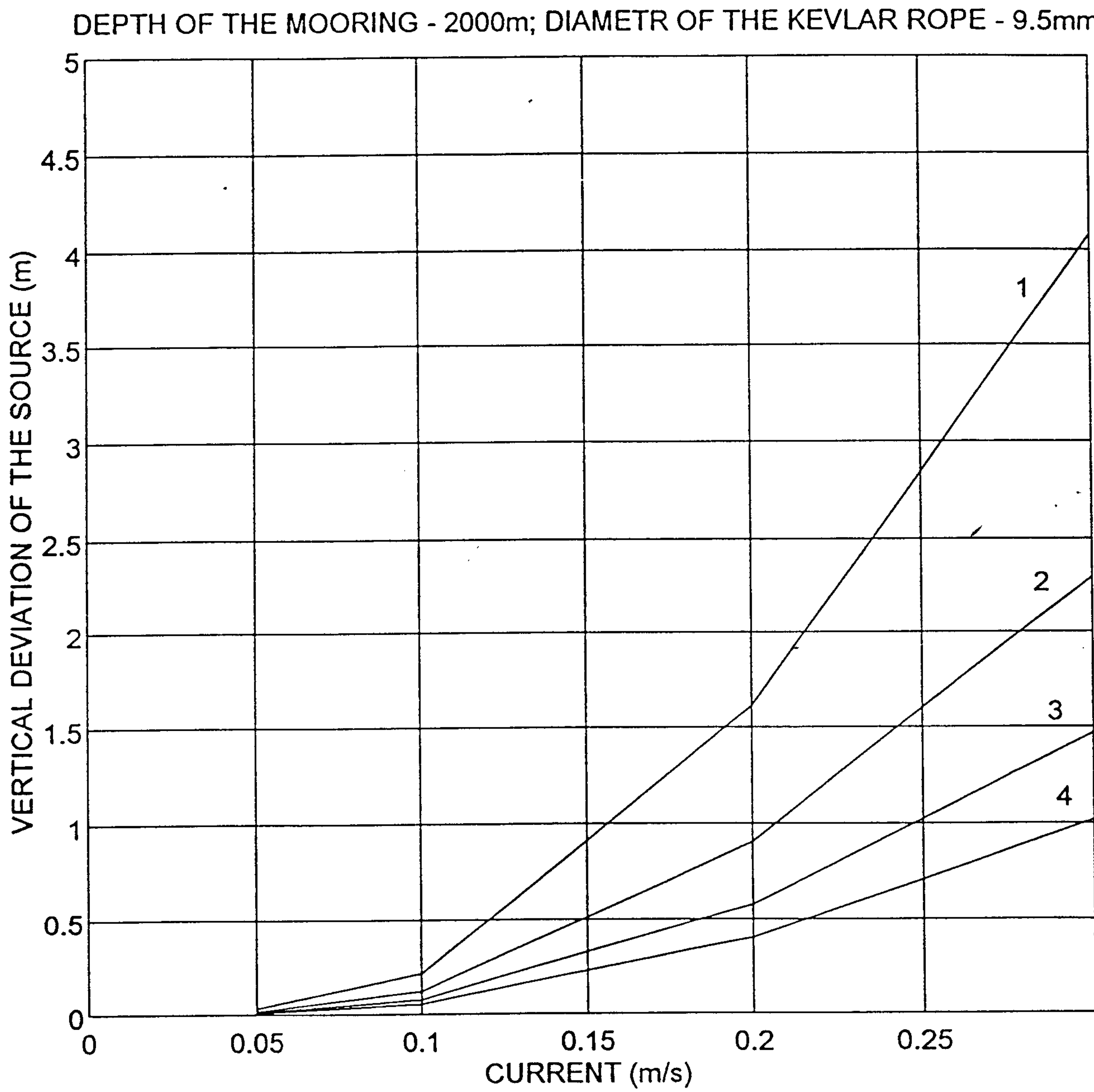

Fig.26. The vertical deviation of the source versus current velocity in deep water, with rope diameter - 9.5 mm, rope length - 500 m, and rope tension: 1 - 15000 N, 2 - 20000 N, 3 - 25000 N, 4 - 30000 N.